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MASH Test Nos. 3-17 and 3-11 on a Non-Proprietary Cable Median Barrier

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Bielenberg, Robert W.; Rosenbaugh, Scott K.; Faller, Ronald K.; Humphrey, Brandt M.; Schmidt, Tyler L.; and Reid, John D., "MASH Test Nos. 3-17 and 3-11 on a Non-Proprietary Cable Median Barrier" (2015). *Nebraska Department of Transportation Research Reports*. 164.
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Midwest States Regional Pooled Fund Research Program
Fiscal Years 2012 and 2014 (Years 22 and 24)
Research Project Number TPF-5(193) sup. 44 and sup. 64
NDOR Sponsoring Agency Code RPFP-14-CABLE-1

MASH TEST NOS. 3-17 AND 3-11 ON A NON-PROPRIETARY CABLE MEDIAN BARRIER

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Submitted to

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Nebraska Department of Roads
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MwRSF Research Report No. TRP-03-303-15

November 3, 2015

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2.	3. Recipient's Accession No.	
TRP-03-303-15			
4. Title and Subtitle MASH Test Nos. 3-17 and 3-11 on a Non-Proprietary Cable Median Barrier		5. Report Date November 3, 2015 6.	
7. Author(s) Bielenberg, R.W., Rosenbaugh, S.K., Faller, R.K., Humphrey, B.M., Schmidt, T.L., Lechtenberg, K.A., and Reid, J.D.		8. Performing Organization Report No. TRP-03-303-15	
9. Performing Organization Name and Address Midwest Roadside Safety Facility (MwRSF) Nebraska Transportation Center University of Nebraska-Lincoln 130 Whittier Research Center 2200 Vine Street Lincoln, Nebraska 68583-0853		10. Project/Task/Work Unit No. 11. Contract © or Grant (G) No. TPF-5(193) sup. 44 TPF-5(193) sup. 64	
12. Sponsoring Organization Name and Address Midwest States Regional Pooled Fund Program Nebraska Department of Roads 1500 Nebraska Highway 2 Lincoln, Nebraska 68502		13. Type of Report and Period Covered Final Report: 2012 – 2015 14. Sponsoring Agency Code RPFP-12-CABLE1&2 RPFP-14-CABLE-1	
15. Supplementary Notes Prepared in cooperation with U.S. Department of Transportation, Federal Highway Administration.			

16. Abstract (Limit: 200 words)

The Midwest States Pooled Fund has been developing a new design for a non-proprietary high-tension cable median barrier. This new system incorporates four evenly spaced cables, Midwest Weak Posts (MWPs) spaced at 8 to 16 ft (2.4 to 4.9 m) intervals, and a bolted, tabbed bracket to attach the cables to the post. Full-scale crash testing was needed to evaluate the barrier's safety performance. According to the proposed *Manual for Assessing Safety Hardware (MASH)* testing matrix for cable barriers installed within a median ditch, a series of eight full-scale tests are required to evaluate the safety performance of the system. Additionally, a ninth test is required to establish the working width for systems with variable post spacings.

Three full-scale crash tests were performed on the cable barrier system for use anywhere within 6H:1V V-ditches. Test no. MWP-1 was conducted according to MASH test no. 3-17 and utilized a 1500A passenger car impacting the barrier at the slope break point. The vehicle was contained and redirected by the barrier, and the test was deemed acceptable. Test no. MWP-2 was conducted according to MASH test no. 3-11 and utilized a 2270P pickup truck impacting the barrier on level terrain. The vehicle was contained and redirected by the barrier, and the test was deemed acceptable. Test no. MWP-3 was also conducted with a 2270P vehicle according to MASH test no. 3-11. However, the post spacing was reduced from 16 ft (4.9 m), utilized during the first two tests, to 8 ft (2.4 m). After initially capturing the vehicle, three cables were eventually overridden as the vehicle was being redirected. Subsequently, the vehicle rolled and the test was deemed unacceptable.

17. Document Analysis/Descriptors		18. Availability Statement	
Highway Safety, Crash Test, MASH, Compliance Test, Longitudinal Barrier, Cable Barrier, Median Barrier, High-Tension, 6H:1V Median V-Ditch		No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161	
19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	293	

DISCLAIMER STATEMENT

This report was completed with funding from the Federal Highway Administration, U.S. Department of Transportation. The contents of this report reflect the views and opinions of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the state highway departments participating in the Midwest States Regional Pooled Fund Program nor the Federal Highway Administration, U.S. Department of Transportation. This report does not constitute a standard, specification, regulation, product endorsement, or an endorsement of manufacturers.

UNCERTAINTY OF MEASUREMENT STATEMENT

The Midwest Roadside Safety Facility (MwRSF) has determined the uncertainty of measurements for several parameters involved in standard full-scale crash testing and non-standard testing of roadside safety features. Information regarding the uncertainty of measurements for critical parameters is available upon request by the sponsor and the Federal Highway Administration.

INDEPENDENT APPROVING AUTHORITY

The Independent Approving Authority (IAA) for the data contained herein was Dr. Jennifer Schmidt, P.E., Research Assistant Professor.

ACKNOWLEDGEMENTS

The authors wish to acknowledge several sources that made a contribution to this project: (1) the Midwest States Regional Pooled Fund Program funded by the Illinois Department of Transportation, Indiana Departement of Transportation, Iowa Department of Transportation, Kansas Department of Transportation, Minnesota Department of Transportation, Missouri Department of Transportation, Nebraska Department of Roads, New Jersey Department of Transportation, Ohio Department of Transportation, South Dakota Department of Transportation, Wisconsin Department of Transportation, and Wyoming Department of Transportation for sponsoring this project; and (2) MwRSF personnel for constructing the barriers and conducting the crash tests.

Acknowledgement is also given to the following individuals who made a contribution to the completion of this research project.

Midwest Roadside Safety Facility

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1 INTRODUCTION

1.1 Background

In recent years, the Midwest States Pooled Fund has been developing a non-proprietary high-tension cable median barrier in conjunction with the Midwest Roadside Safety Facility (MwRSF). The design of the cable median barrier system had progressed through a series of crash tests that identified flaws in the system related to capturing vehicles traveling within a median V-ditch and to excessive occupant compartment deformations of sedans [1-3]. These performance issues highlighted the need to develop new barrier components to improve the safety performance of the cable median barrier.

Several design changes were made to improve system performance and satisfy the Manual for Assessing Safety Hardware (MASH) TL-3 safety requirements for cable median barrier [4]. First, the top cable attachment was modified to alleviate vehicle override concerns when the barrier was placed down the front slope of a depressed median. During test no. 4CMB-5, the vehicle impacted the system at a post, which pulled down the top cable and allowed the vehicle to override the barrier system [2]. To prevent this behavior, a new top cable attachment was developed, in which the cable resided within a V-notch cut into the top of the post and held in place with a brass keeper rod. Component testing demonstrated that the cable would be quickly released during impacts to the post, thus preventing the cable from being pulled down and preventing vehicle override [5-7].

Second, a new post section was developed to reduce the lateral stiffness of each support post. Test no. 4CMBLT-1 resulted in the upper cables crushing the A-pillar of an impacting sedan while the vehicle was being redirected [3]. Review of the full-scale test illustrated that the posts immediately downstream from the vehicle were not yielding and bending over prior to the vehicle impacting them. Thus, the upper cables formed steep angles as they ran between the downstream post and the vehicle A-pillar during redirection. The combination of this angle and the tensile load in the cables resulted in high loads being imparted to the A-pillar and, eventually, the A-pillar crushing inward. Therefore, a new post section, the Midwest Weak Post (MWP), was developed to be more forgiving and reduce the lateral force required to bend a post. Component testing demonstrated that the MWP had approximately half of the strong-axis bending strength of the previous S3x5.7 (S76x8.5) posts [8]. Thus, MWPs should yield and bend over prior to the cables forming steep angles and imparting high loads to the vehicle A-pillar. Furthermore, the cable tension was decreased from 4,200 lb (18.7 kN) at 100 degrees Fahrenheit to 2,500 lb (11.1 kN) at 100 degrees Fahrenheit. Cable tension was expected to decrease occupant compartment penetration and reduce A-pillar crush [5].

Additionally, review of the behavior of the old cable barrier design found that the performance of the cable-to-post attachment clips was not optimized. The attachments appeared to be too strong vertically to release cables safely and effectively. Additionally, it was observed that the lateral release forces were not sufficient to yield and displace the posts in the system, thus limiting the amount of energy absorbed by the barrier during impact. Through an extensive research and development phase, new bolted-tabbed brackets were developed to optimize the cable-to-post release loads. These brackets provided only a third of the vertical release load of the previous clips, while also providing enough lateral strength to allow the MWP to yield [5].

The cable barrier system was originally targeted for placement anywhere within a 4H:1V median V-ditch. However, the unsuccessful testing of the original system led the sponsors and developers of the barrier to reuse the slope criteria for the barriers . Subsequently, the design criteria was lessened to placement anywhere within a 6H:1V V-ditch. The cable heights were adjusted accordingly to reflect the reduced envelope of possible vehicle impact heights into the system [6]. The top cable height was reduced from 45 in. (1,142 mm) to 40 in. (1,016 mm) and the vertical cable spacing was reduced from 10½ in. (267 mm) to 8¾ in. (222 mm).

After the barrier components had been redesigned to improve system performance, the cable barrier system needed to be evaluated through full-scale crash testing. This report highlights the first three full-scale tests conducted on the redesigned non-proprietary four-cable median barrier system according to the MASH Test Level 3 (TL-3) criteria [4].

1.2 Research Objectives

The primary objective of this project was to evaluate a high-tension four-cable median barrier that satisfies MASH TL-3 criteria when placed anywhere within 6H:1V median V-ditches.

1.3 Research Scope

Evaluation of the non-proprietary four-cable median barrier began with the three full-scale crash tests documented herein. The first test was proposed MASH test designation no. 3-17 conducted with a 3,300-lb (1,500-kg) sedan impacting at a speed of 62 mph (100 km/h) and an angle of 25 degrees. The barrier was placed at the slope break point of a 6H:1V slope to optimize the probability of vehicle penetration between adjacent cables. The second and third tests were MASH test designation no. 3-11 conducted with 5,000-lb (2,270-kg) pickup trucks impacting at a speed of 62 mph (100 km/h) and at an angle of 25 degrees on level terrain. The two MASH test designation no. 3-11 tests were conducted to establish the barrier's working width utilizing 16-ft and 8-ft (4.9-m and 2.4-m) post spacing configurations. The results from all three tests were analyzed, evaluated, and documented. Conclusions and recommendations were then made pertaining to the safety performance of the new cable barrier system.

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

Longitudinal barriers, such as cable median barriers, must satisfy impact safety standards in order to be declared eligible for federal reimbursement by the Federal Highway Administration (FHWA) for use on the National Highway System (NHS). For new hardware, these safety standards consist of the guidelines and procedures published in MASH [4]. Note that current longitudinal barrier testing in MASH is for level terrain. However, recent development of cable median barrier systems on slopes has led to the development of a proposed test matrix for cable median barriers in V-ditches. According to the proposed MASH testing matrix for cable barriers placed anywhere within median V-ditches, the barrier system must be subjected to eight full-scale vehicle crash tests. Although the impact speed and angle are consistent for all eight tests, the critical location of the barrier system within the median ditch is dependent upon the specific crash test and the size/slope of the ditch. The proposed MASH TL-3 testing matrix for a cable median barrier system designed for placement anywhere within a 6H:1V or flatter V-ditch is shown in Table 1. Note, the proposed MASH update specifies that barrier systems designed for 6H:1V V-ditches are to be tested within a 30-ft (9.1-m) wide, 6H:1V V-ditch.

Many cable barrier systems have variable post spacings which allow roadside designers to select the optimal configuration for a specific installation. When evaluating these variable post spacing systems, the critical post spacing should be utilized during crash testing. The proposed MASH update has identified the critical post spacing, either the narrowest or the widest spacing, for each individual test within the testing matrix. However, since the 2270P test on level terrain is utilized to establish the working width of the system, proposed MASH test designation no. 3-11 must be conducted with both the narrowest and the widest post spacings to establish the working width bounds of the barrier system. It is for this reason that multiple proposed MASH test designation no. 3-11 tests were conducted on the new non-proprietary four-cable median barrier.

In accordance with MASH requirements, the critical impact point for the 2270P vehicle was 12 in. (305 mm) upstream of a post. The critical impact point for the 1500A vehicle in test no. 3-17 was determined to be located at the midspan between posts. This impact location was determined to maximize the potential for vehicle penetration by allowing the vehicle to split the cables.

When non-symmetrical cable barriers are tested, it is important to test the orientation that produces the greatest risk of failure. To accomplish this, the orientation of the cables was selected such that primary capture cable would be located on the non-impact side of the post. The primary capture cable for the 2270P vehicle was determined to be the third cable from the bottom. Selecting this orientation allowed for the greatest risk of failure due to the post pushing the backside cables down and preventing vehicle capture. This would then allow the vehicle to overrun the barrier. The primary capture cable for the 1500A vehicle was determined to be the second cable form the bottom. Selecting this orientation allowed for the greatest risk of failure delaying vehicle interlock with the barrier and increasing the potential for the vehicle to penetrate the system.

Table 1. Proposed MASH TL-3 Test Matrix for Barrier Placement Anywhere Within a 6V:1H V-Ditch

Test No.	Test Vehicle	Vehicle Weight, lb (kg)	Impact Conditions		System Configuration		Evaluation Criteria [2]
			Speed, mph (km/h)	Angle, deg.	System Location [1]	Post Spacing	
3-10	1100C	2,425 (1,100)	62 (100)	25	Level Terrain	Narrow	A,D,F,H,I
3-11	2270P	5,000 (2,270)	62 (100)	25	Level Terrain	Both	A,D,F,H,I
3-13	2270P	5,000 (2,270)	62 (100)	25	9 ft Down Front Slope	Narrow	A,D,F,H,I
3-14	1100C	2,425 (1,100)	62 (100)	25	9 ft Down Front Slope	Narrow	A,D,F,H,I
3-15	1100C	2,425 (1,100)	62 (100)	25	4 ft Up Back Slope	Wide	A,D,F,H,I
3-16	1100C	2,425 (1,100)	62 (100)	25	1 ft Down Back Slope	Narrow	A,D,F,H,I
3-17	1500A	3,300 (1,500)	62 (100)	25	See Note [3]	Wide	A,D,F,H,I
3-18	2270P	5,000 (2,270)	62 (100)	25	At Back Slope Break Point	Wide	A,D,F,H,I

[1] Test nos. 3-13 through 3-18 shall be conducted within a 30-ft (9.1-m) wide, 6H:1V V-ditch
[2] Evaluation criteria explained in Table 2.
[3] Testing laboratory to determine critical barrier position on front slope of ditch to maximize propensity for front end of 1500A vehicle to penetrate between vertically adjacent cables.

2.2 Evaluation Criteria

Evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy, (2) occupant risk, and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of the cable median barrier to contain and redirect impacting vehicles. In addition, controlled lateral deflection of the test article is acceptable. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Post-impact vehicle trajectory is a measure of the potential of the vehicle to result in a secondary collision with other vehicles and/or fixed objects, thereby increasing the risk of injury to the occupants of the impacting vehicle and/or other vehicles. These evaluation criteria are summarized in Table 2 and defined in greater detail in MASH. The full-scale vehicle crash tests were conducted and reported in accordance with the procedures provided in MASH.

In addition to the standard occupant risk measures, the Post-Impact Head Deceleration (PHD), the Theoretical Head Impact Velocity (THIV), and the Acceleration Severity Index (ASI) were determined and reported on the test summary sheet. Additional discussion on PHD, THIV and ASI is provided in MASH.

Table 2. MASH Evaluation Criteria for Longitudinal Barrier

<table>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td></tr>
<tr><td rowspan="10">Occupant Risk</td><td>D.</td><td colspan="3">Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s
(9.1 m/s)</td><td>40 ft/s
(12.2 m/s)</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
</table>

2.3 Soil Strength Requirements

In accordance with Chapter 3 and Appendix B of MASH, foundation soil strength must be verified before any full-scale crash testing can occur. During the installation of a soil dependent system, additional W6x16 (W152x23.8) posts are to be installed near the impact region utilizing the same installation procedures as the system itself. Prior to full-scale testing, a dynamic impact test must be conducted to verify a minimum dynamic soil resistance of 7.5 kips (33.4 kN) at post deflections between 5 and 20 in. (127 and 508 mm) measured at a height of 25 in. (635 mm). If dynamic testing near the system is not desired, MASH instead permits a static test to be conducted and compared against the results of a previously established baseline test. In this situation, the soil must provide a resistance of at least 90 percent of the static baseline test at deflections of 5, 10, and 15 in. (127, 254, and 381 mm). Further details can be found in Appendix B of MASH.

3 TEST CONDITIONS

3.1 Test Facility

The testing facility is located at the Lincoln Air Park on the northwest side of the Lincoln Municipal Airport, and is approximately 5 miles (8.0 km) northwest of the city campus of the University of Nebraska-Lincoln.

3.2 Vehicle Tow and Guidance System

A reverse cable tow system with a 1:2 mechanical advantage was used to propel the test vehicle. The distance traveled and the speed of the tow vehicle were one-half those of the test vehicle. The test vehicle was released from the tow cable before impact with the barrier system. A digital speedometer on the tow vehicle increased the accuracy of the test vehicle impact speed.

A vehicle guidance system developed by Hinch [9] was used to steer the test vehicle. A guide flag, attached to the left-front wheel and the guide cable, was sheared off before impact with the barrier system. The ⅜-in. (9.5-mm) diameter guide cable was tensioned to approximately 3,500 lb (15.6 kN) and supported both laterally and vertically every 100 ft (30.5 m) by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide flag struck and knocked each stanchion to the ground.

3.3 Test Vehicles

For test no. MWP-1, a 2006 Ford Taurus was used as the test vehicle. This vehicle model was selected for three reasons: (1) it fit the requirements for a MASH 1500A test vehicle, (2) in a previous analysis of real-world cable crashes, Taurus impacts into cable barriers were found to result in abnormally high penetration rates [10], and (3) it had one of the narrowest front end geometry heights of all popular sedan models on United States roadways. Thus, the Ford Taurus represented a critical vehicle model for evaluating penetration through a cable barrier system.

The curb, test inertial, and gross static vehicle weights were 3,205 lb (1,454 kg), 3,298 lb (1,496 kg), and 3,462 lb (1,570 kg), respectively. The test vehicle is shown in Figure 1, and vehicle dimensions are shown in Figure 2.

For test no. MWP-2, a 2008 Dodge Ram was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,058 lb (2,294 kg), 5,023 lb (2,278 kg), and 5,189 lb (2,354 kg), respectively. The test vehicle is shown in Figure 3, and vehicle dimensions are shown in Figure 4.

For test no. MWP-3, a 2007 Dodge Ram was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,074 lb (2,302 kg), 4,992 lb (2,264 kg), and 5,158 lb (2,340 kg), respectively. The test vehicle is shown in Figure 5, and vehicle dimensions are shown in Figure 6.

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The vertical component of the c.g. for the 1500A vehicle was determined utilizing a procedure published by the Society of Automotive Engineers (SAE) [11]. The Suspension Method [12] was used to determine the vertical component of the c.g. for the 2270P vehicles. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The vehicle was suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the final c.g. location for the test inertial condition. The locations of the c.g.'s for test nos. MWP-1 through MWP-3 are shown in Figures 2, 4, and 6, respectively. Data used to calculate the locations of the c.g.'s and ballast information are shown in Appendix B.

Square, black and white-checkered targets were placed on the vehicles for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in Figures 7 through 9 for test nos. MWP-1 through MWP-3, respectively. Round, checkered targets were placed on the centers of gravity on the left-side doors, the right-side doors, and the roofs of the vehicles.

The front wheels of the test vehicles were aligned to vehicle standards except the toe-in value was adjusted to zero so that the vehicles would track properly along the guide cable. A 5B flash bulb was mounted on the left side of each vehicle's dash and was fired by a pressure tape switch mounted at the impact corner of the bumper. The flash bulb was fired upon initial impact with the test article to create a visual indicator of the precise time of impact on the high-speed videos. A remote controlled brake system was installed in the test vehicles so the vehicles could be brought safely to a stop after each test.

3.4 Simulated Occupant

A Hybrid II 50th-Percentile, Adult Male Dummy, equipped with clothing and footwear, was placed in the left-front seat of all three test vehicles with the seat belts fastened. The dummy, which had an approximate weight of 165 lb (75 kg), was represented by model no. 572, serial no. 451, and was manufactured by Android Systems of Carson, California. As recommended by MASH, the dummy was not included in calculating the c.g locations.

3.5 Data Acquisition Systems

3.5.1 Accelerometers

Two environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. Both accelerometers were mounted near the center of gravity of each test vehicle. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filters conforming to the SAE J211/1 specifications [13].

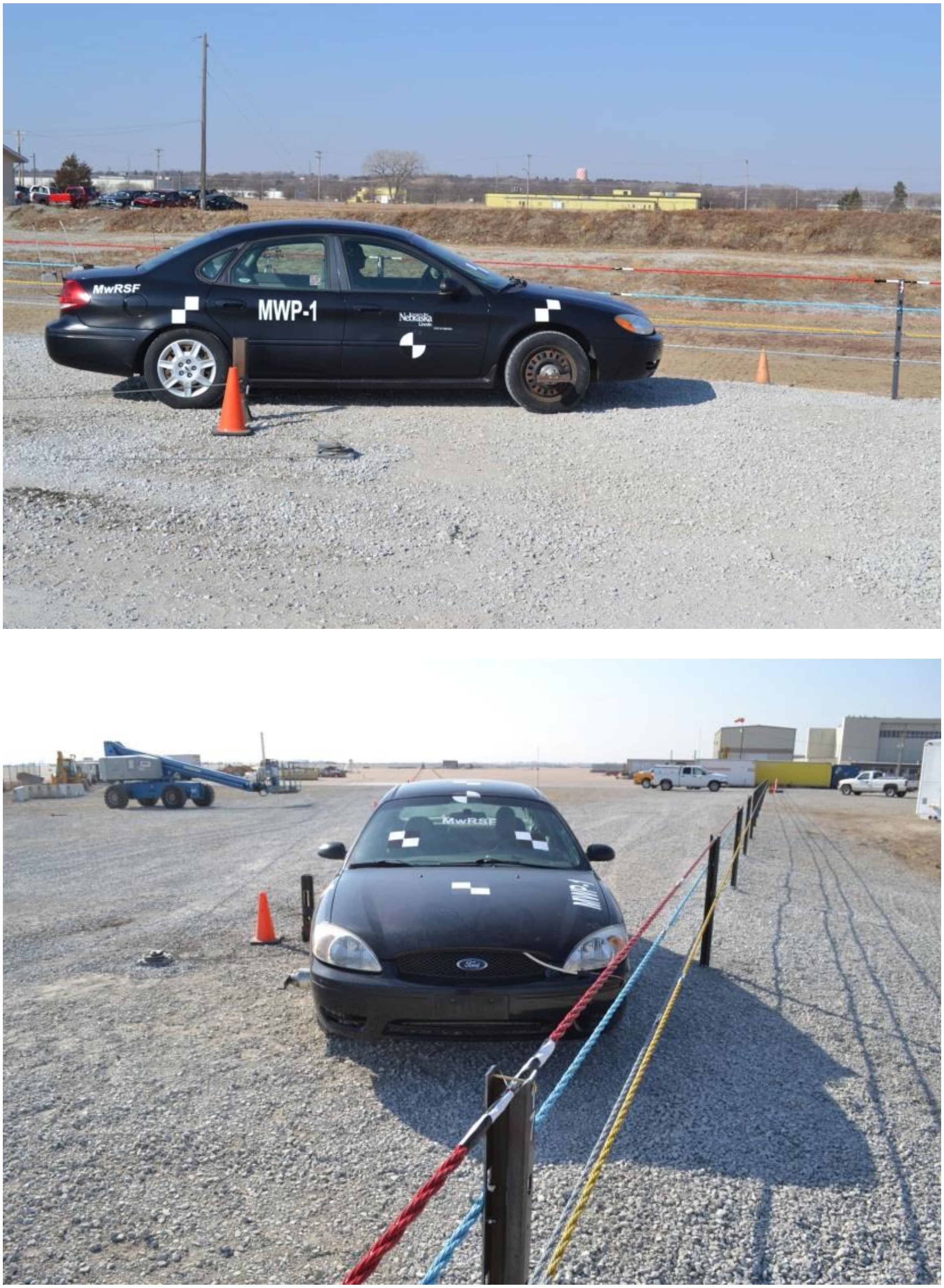
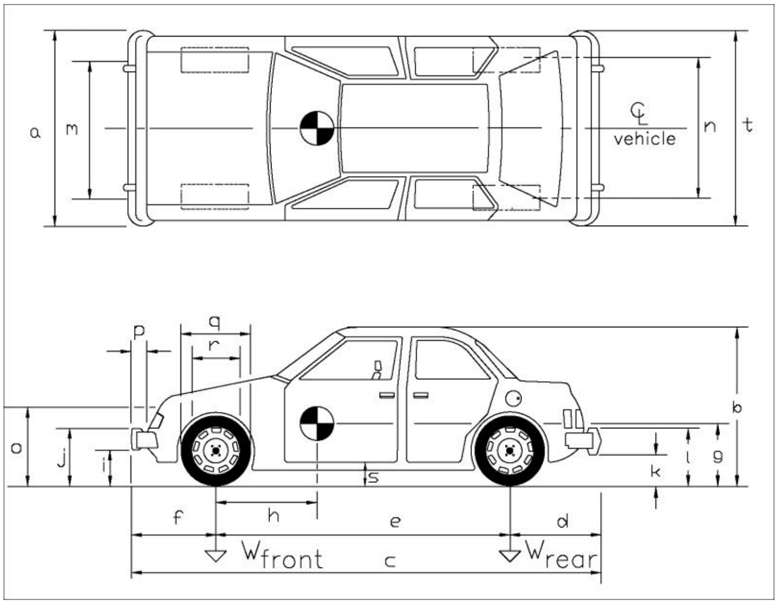


Figure 1. Test Vehicle, Test No. MWP-1

Date:	**3/26/2014**	**Test Number:**	**MWP-1**	**Model:**	**taurus**
Make:	**FORD**	**Vehicle I.D.#:**	**1FAFP53U16A147065**		
Tire Size:	**P215/60R16**	**Year:**	**2006**	**Odometer:**	**73050**

Tire Inflation Pressure: **30**

***(All Measurements Refer to Impacting Side)**



Vehicle Geometry -- in. (mm)

a	**68 3/4**	**(1746)**	**b**	**57 3/4**	**(1467)**
c	**197 3/4**	**(5023)**	**d**	**47 1/2**	**(1207)**
e	**108 1/2**	**(2756)**	**f**	**41 3/4**	**(1060)**
g	**21 1/4**	**(540)**	**h**	**40 1/4**	**(1023)**
i	**10 1/2**	**(267)**	**j**	**23**	**(584)**
k	**13 1/4**	**(337)**	**l**	**26**	**(660)**
m	**60 3/4**	**(1543)**	**n**	**62**	**(1575)**
o	**29**	**(737)**	**p**	**4 1/2**	**(114)**
q	**26**	**(660)**	**r**	**17 1/2**	**(445)**
s	**10 1/2**	**(267)**	**t**	**69 1/4**	**(1759)**

Wheel Center Height Front	**12 1/4**	**(311)**
Wheel Center Height Rear	**12 1/2**	**(318)**
Wheel Well Clearance (F)	**28**	**(711)**
Wheel Well Clearance (R)	**26 1/2**	**(673)**
Frame Height (F)	**7**	**(178)**
Frame Height (R)	**16**	**(406)**
Engine Type	**V-6**	
Engine Size	**3.0L**	

Transmission Type:

Automatic **Manual**

FWD **RWD** **4WD**

Mass Distribution lb (kg)

Gross Static	**LF**	**1092 (495)**	**RF**	**1066 (484)**
	LR	**661 (300)**	**RR**	**643 (292)**

Weights lb (kg)	**Curb**	**Test Inertial**	**Gross Static**
W-front	**2115 (959)**	**2074 (941)**	**2158 (979)**
W-rear	**1090 (494)**	**1224 (555)**	**1304 (591)**
W-total	**3205 (1454)**	**3298 (1496)**	**3462 (1570)**

GVWR Ratings

Front	**2552**
Rear	**2132**
Total	**4684**

Dummy Data

Type:	**Hybrid**
Mass:	**164**
Seat Position:	**Driver**

Note any damage prior to test: **HAIL**

Figure 2. Vehicle Dimensions, Test No. MWP-1

Figure 3. Test Vehicle, Test No. MWP-2

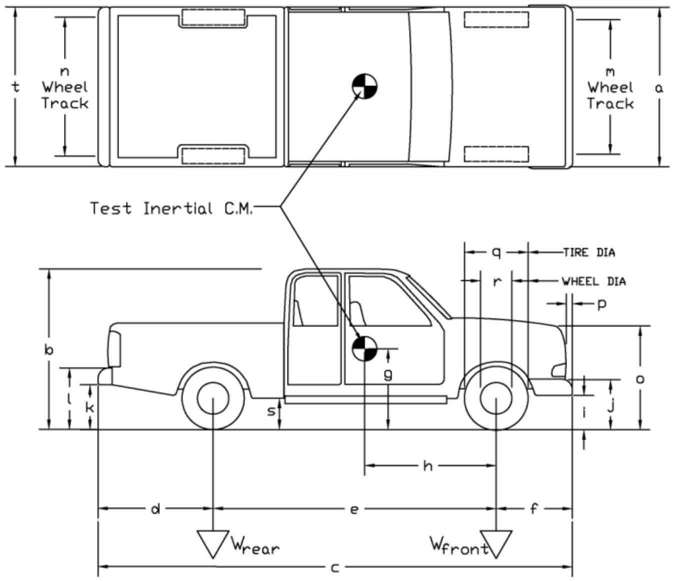
Date: 4/18/2014 **Test Number:** MWP-2 **Model:** Ram 1500

Make: Dodge **Vehicle I.D.#:** 1D7HA18N28S611689

Tire Size: 275/60 R20 **Year:** 2008 **Odometer:** 140962

Tire Inflation Pressure: 35 psi

***(All Measurements Refer to Impacting Side)**



Vehicle Geometry -- in. (mm)

a	77 3/4	(1975)	b	75	(1905)
c	228 1/4	(5798)	d	44 3/4	(1137)
e	140 1/2	(3569)	f	43	(1092)
g	28 1/2	(724)	h	61 3/8	(1559)
i	12	(305)	j	27 3/4	(705)
k	20 3/4	(527)	l	29	(737)
m	68 1/4	(1734)	n	66	(1676)
o	46 3/4	(1187)	p	3	(76)
q	31 1/2	(800)	r	18 1/2	(470)
s	15 1/2	(394)	t	75	(1905)

Wheel Center Height Front	14 3/4	(375)
Wheel Center Height Rear	15	(381)
Wheel Well Clearance (F)	35 1/2	(902)
Wheel Well Clearance (R)	38	(965)
Frame Height (F)	18 1/2	(470)
Frame Height (R)	25 1/4	(641)
Engine Type	8cyl Gas	
Engine Size	4.7L	

Transmition Type:

Automatic Manual

FWD RWD 4WD

Mass Distribution lb (kg)

Gross Static	LF	1531	(694)	RF	1400	(635)
	LR	1117	(507)	RR	1141	(518)

Weights lb (kg)	Curb		Test Inertial		Gross Static	
W-front	2871	(1302)	2829	(1283)	2931	(1329)
W-rear	2187	(992)	2194	(995)	2258	(1024)
W-total	5058	(2294)	5023	(2278)	5189	(2354)

GVWR Ratings

Front	3700
Rear	3900
Total	6700

Dummy Data

Type: Hybrid II

Mass: 166 lbs

Seat Position: Driver

Note any damage prior to test: None

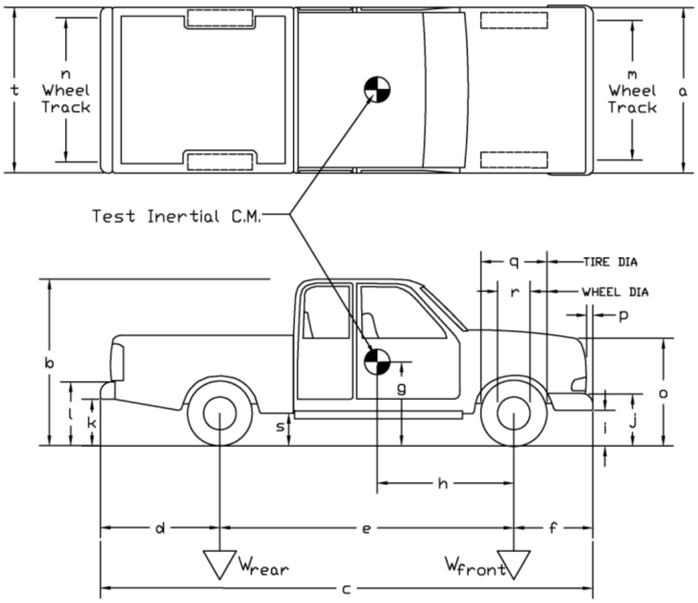
Figure 4. Vehicle Dimensions, Test No. MWP-2

Figure 5. Test Vehicle, Test No. MWP-3

Date:	**7/11/2014**	**Test Number:**	**MWP-3**	**Model:**	**2270P**
Make:	**Dodge Ram**	**Vehicle I.D.#:**	**1D7HA18P47J552280**		
Tire Size:	**265/70 R17**	**Year:**	**2007**	**Odometer:**	**144031**

Tire Inflation Pressure: **35psi**

***(All Measurements Refer to Impacting Side)**



Vehicle Geometry -- in. (mm)

a	**78**	**(1981)**	**b**	**75 3/8**	**(1915)**
c	**227 1/2**	**(5779)**	**d**	**47 1/2**	**(1207)**
e	**140 1/2**	**(3569)**	**f**	**39 1/2**	**(1003)**
g	**28 2/9**	**(717)**	**h**	**62 1/2**	**(1588)**
i	**16**	**(406)**	**j**	**29**	**(737)**
k	**20**	**(508)**	**l**	**28**	**(711)**
m	**68 1/2**	**(1740)**	**n**	**67 5/8**	**(1718)**
o	**45**	**(1143)**	**p**	**3 1/2**	**(89)**
q	**31 1/2**	**(800)**	**r**	**18 1/2**	**(470)**
s	**16**	**(406)**	**t**	**75**	**(1905)**

Wheel Center Height Front	**15 1/8**	**(384)**
Wheel Center Height Rear	**15**	**(381)**
Wheel Well Clearance (F)	**35 1/4**	**(895)**
Wheel Well Clearance (R)	**37 1/2**	**(953)**
Frame Height (F)	**18 3/4**	**(476)**
Frame Height (R)	**24 7/8**	**(632)**
Engine Type	**8 cyl. Gas**	
Engine Size	**4.7L**	

Transmition Type:

Automatic **Manual**

FWD **RWD** **4WD**

Mass Distribution lb (kg)

Gross Static	**LF**	**1480 (671)**	**RF**	**1390 (630)**
	LR	**1167 (529)**	**RR**	**1121 (508)**

Weights lb (kg)	**Curb**	**Test Inertial**	**Gross Static**
W-front	**2832 (1285)**	**2770 (1256)**	**2870 (1302)**
W-rear	**2242 (1017)**	**2222 (1008)**	**2288 (1038)**
W-total	**5074 (2302)**	**4992 (2264)**	**5158 (2340)**

GVWR Ratings

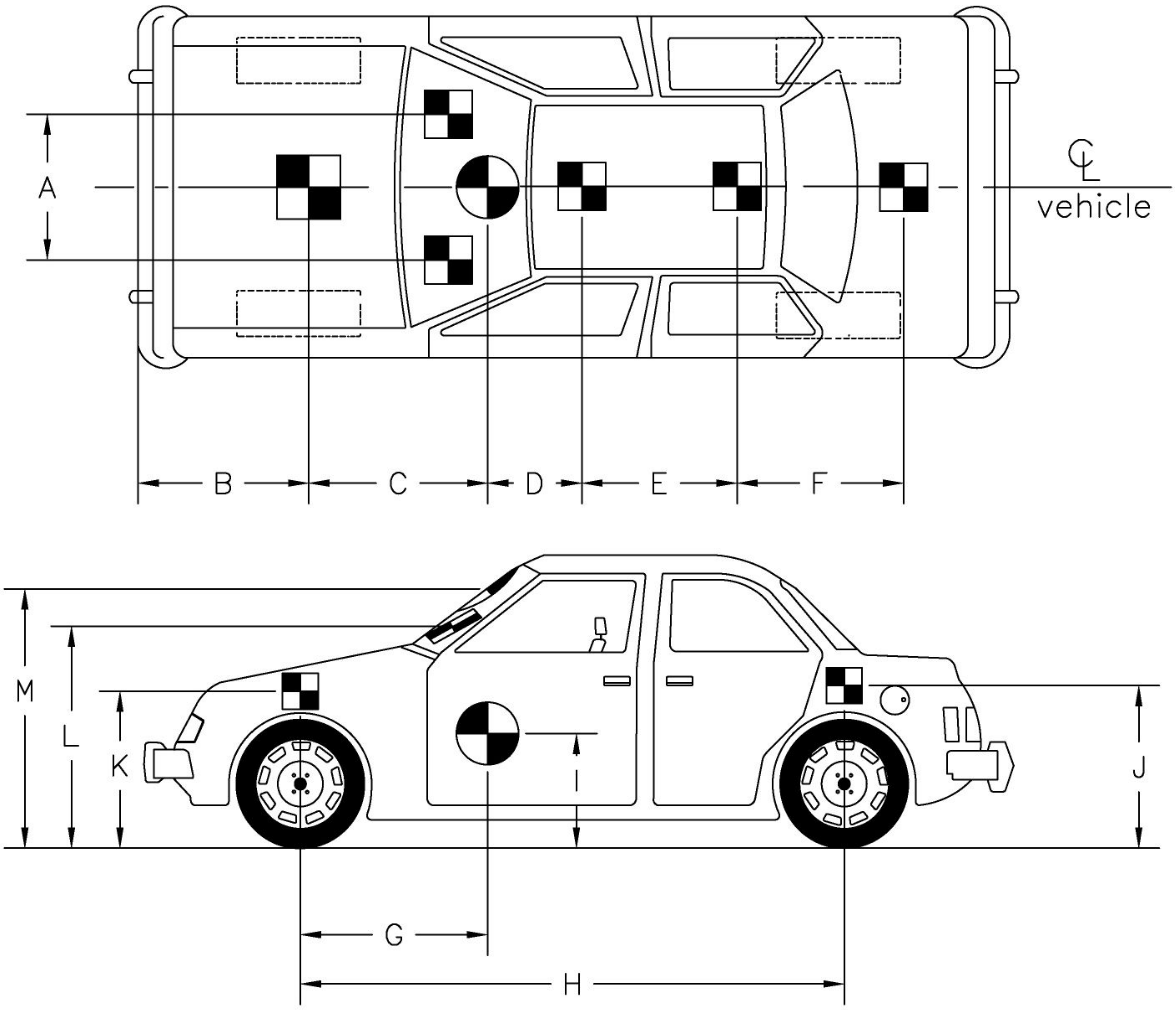
Front	**3700**
Rear	**3900**
Total	**6700**

Dummy Data

Type:	**Hybrid II**
Mass:	**166 lbs**
Seat Position:	**Driver**

Note any damage prior to test: **shallow dent along bottom of passenger front door. Dent in front bumper**

Figure 6. Vehicle Dimensions, Test No. MWP-3

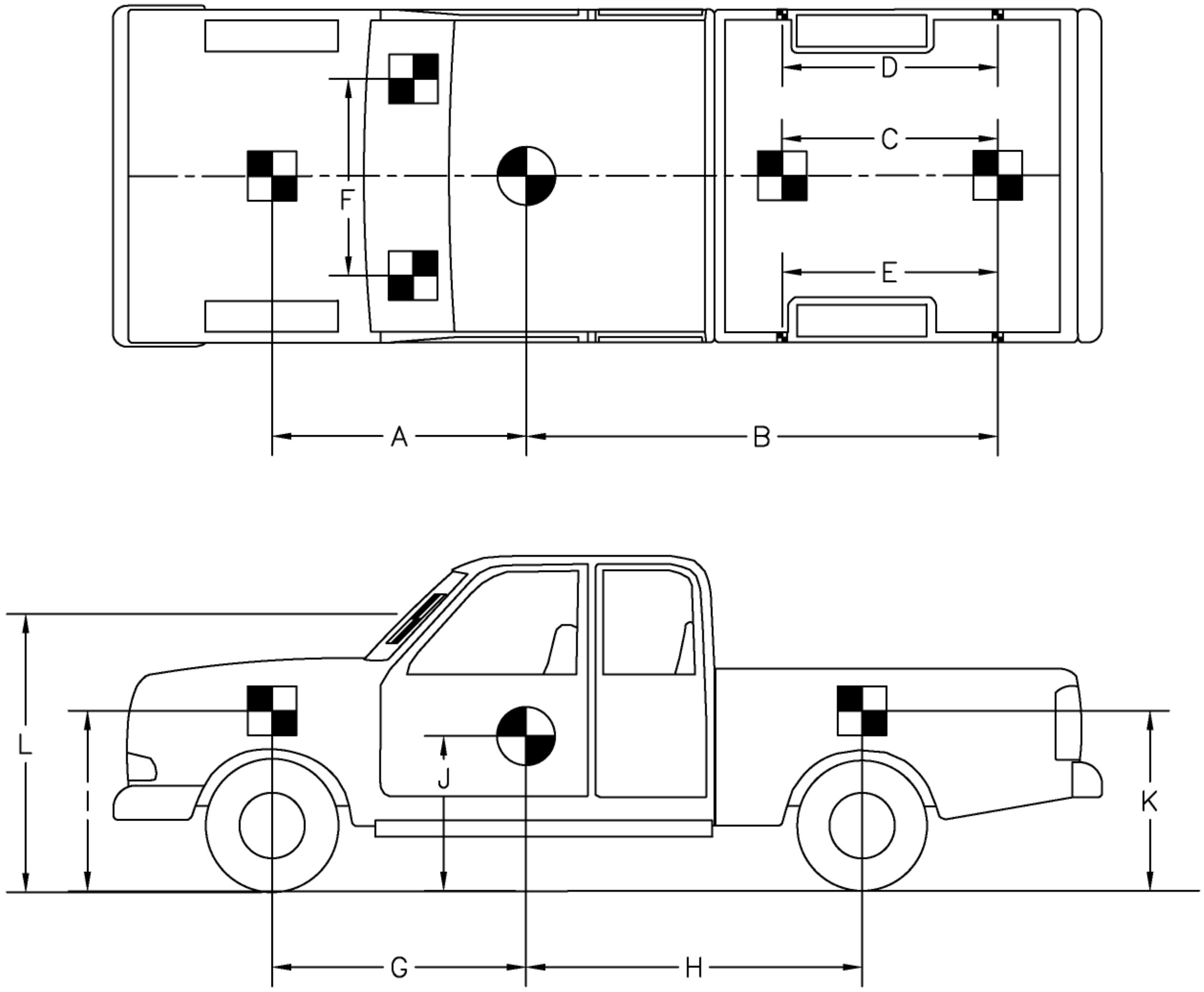


TEST #: MWP-1

TARGET GEOMETRY-- in. (mm)

A	**32 1/2**	**(826)**	**E**	**43 1/2**	**(1105)**	**I**	**21 1/4**	**(540)**
B	**28 1/2**	**(724)**	**F**	**36 1/2**	**(927)**	**J**	**31**	**(787)**
C	**50 3/4**	**(1289)**	**G**	**40 3/4**	**(1035)**	**K**	**31 3/4**	**(806)**
D	**16 1/4**	**(413)**	**H**	**108 1/2**	**(2756)**	**L**	**43**	**(1092)**
						M	**53**	**(1346)**

Figure 7. Target Geometry, Test No. MWP-1

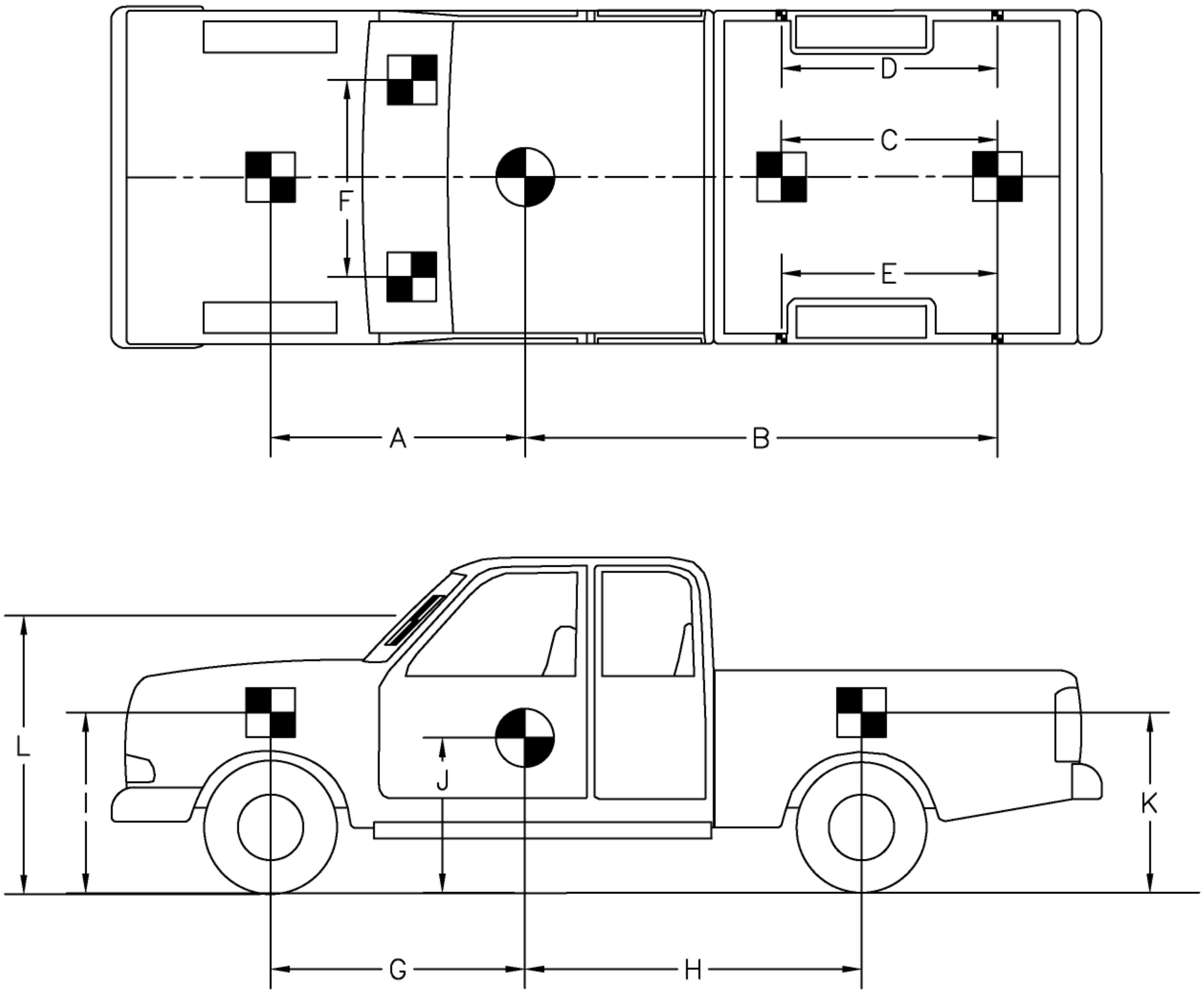


TEST #: MWP-2

TARGET GEOMETRY-- in. (mm)

A	**78 1/2**	**(1994)**	**E**	**66**	**(1676)**	**I**	**39 3/4**	**(1010)**
B	**107 1/2**	**(2731)**	**F**	**43 1/4**	**(1099)**	**J**	**28 1/2**	**(724)**
C	**47 3/4**	**(1213)**	**G**	**61 1/4**	**(1556)**	**K**	**42 1/2**	**(1080)**
D	**66**	**(1676)**	**H**	**79 1/4**	**(2013)**	**L**	**59 1/2**	**(1511)**

Figure 8. Target Geometry, Test No. MWP-2



TEST #: MWP-3

TARGET GEOMETRY-- in. (mm)

A	**78**	**(1981)**	**E**	**64**	**(1626)**	**I**	**39 1/2**	**(1003)**
B	**102 1/2**	**(2604)**	**F**	**33 1/4**	**(845)**	**J**	**28 1/4**	**(718)**
C	**48**	**(1219)**	**G**	**62 1/2**	**(1588)**	**K**	**41 3/4**	**(1060)**
D	**64**	**(1626)**	**H**	**77 3/4**	**(1975)**	**L**	**59**	**(1499)**

Figure 9. Target Geometry, Test No. MWP-3

The accelerometer systems, the SLICE-1 and SLICE-2 units, were modular data acquisition systems manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. The acceleration sensors were mounted inside the bodies of the custom-built SLICE 6DX event data recorders and recorded data at 10,000 Hz to the onboard microprocessor. Each SLICE 6DX was configured with 7 GB of non-volatile flash memory, a range of ±500 g's, a sample rate of 10,000 Hz, and a 1,650 Hz (CFC 1000) anti-aliasing filter. The "SLICEWare" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data. SLICE-2 was designated as the primary unit for test nos. MWP-1 through MWP-3.

3.5.2 Rate Transducers

Two identical angle rate sensor systems mounted inside the bodies of the SLICE-1 and SLICE-2 event data recorders were used to measure the rates of rotation of the vehicles. Each SLICE MICRO Triax ARS unit had a range of 1,500 degrees/sec in each of the three directions (roll, pitch, and yaw) and recorded data at 10,000 Hz to the onboard microprocessor. The raw data measurements were then downloaded, converted to the proper Euler angles for analysis, and plotted. The "SLICEWare" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate sensor data.

3.5.3 Retroreflective Optic Speed Trap

The retroreflective optic speed trap was used to determine the speed of the test vehicles before impact. Five retroreflective targets, spaced at approximately 18-in. (457-mm) intervals, were applied to the sides of the vehicles. When the emitted beam of light was reflected by the targets and returned to the Emitter/Receiver, a signal was sent to the data acquisition computer, which recorded at 10,000 Hz, as well as activated the external LED box. The speed was then calculated using the spacing between the retroreflective targets and the time between the signals.

LED lights and high-speed digital video analysis are only used as a backup in the event that vehicle speeds cannot be determined from the electronic data.

3.5.4 Load Cells and String Potentiometers

Load cells were spliced into each cable upstream from the point of impact. The load cells were located between post nos. 4 and 5 for test nos. MWP-1 and MWP-2, and between post nos. 6 and 8 for test no. MWP-3. All four load cells were Transducer Techniques model no. TLL-50K, with a load range of up to 50 kips (222 kN). A string potentiometer was also attached to the upstream anchor foundation, labeled as post no. 1, for all three tests. The string potentiometer was a Unimeasure model no. PA-50-70124, with a displacement range of up to 50 in. (127 cm). During testing, output voltage signals were sent from the five transducers to a National Instruments PCI-6071E data acquisition board, acquired with LabView software, and stored on a personal computer at a sample rate of 10,000 Hz. The positioning and set up of the system transducers are shown in Figure 10.

Load Cells, Test Nos. MWP-1 and MWP-3

String Potentiometer, Test Nos. MWP-1 through MWP-3

Figure 10. Locations of Load Cells and String Potentiometer

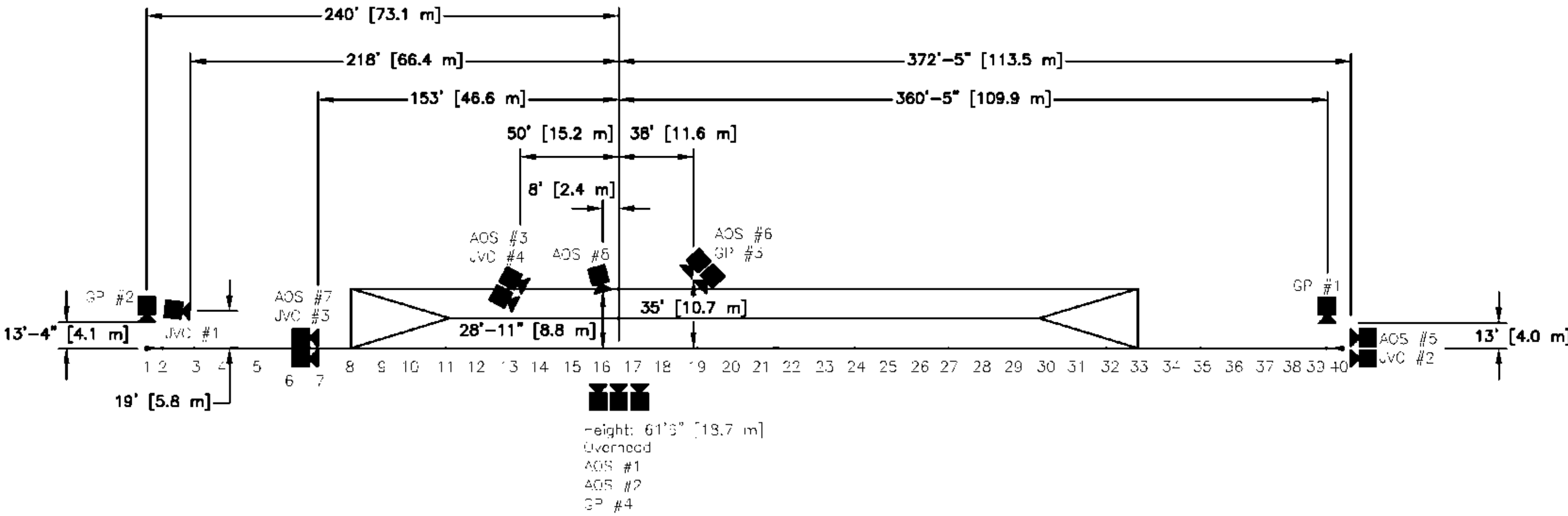
3.5.5 Digital Photography

Four AOS VITcam high-speed digital video cameras, three AOS X-PRI high-speed digital video cameras, four JVC digital video cameras, two GoPro Hero 3+ digital video cameras, and two GoPro Hero 3 digital video cameras were utilized to film test no. MWP-1. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 11.

Two AOS VITcam high-speed digital video cameras, one AOS S-VIT 1531 high-speed digital video camera, three AOS X-PRI high-speed digital video cameras, four JVC digital video cameras, two GoPro Hero 3+ digital video cameras, and two GoPro Hero 3 digital video cameras were utilized to film test no. MWP-2. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 12.

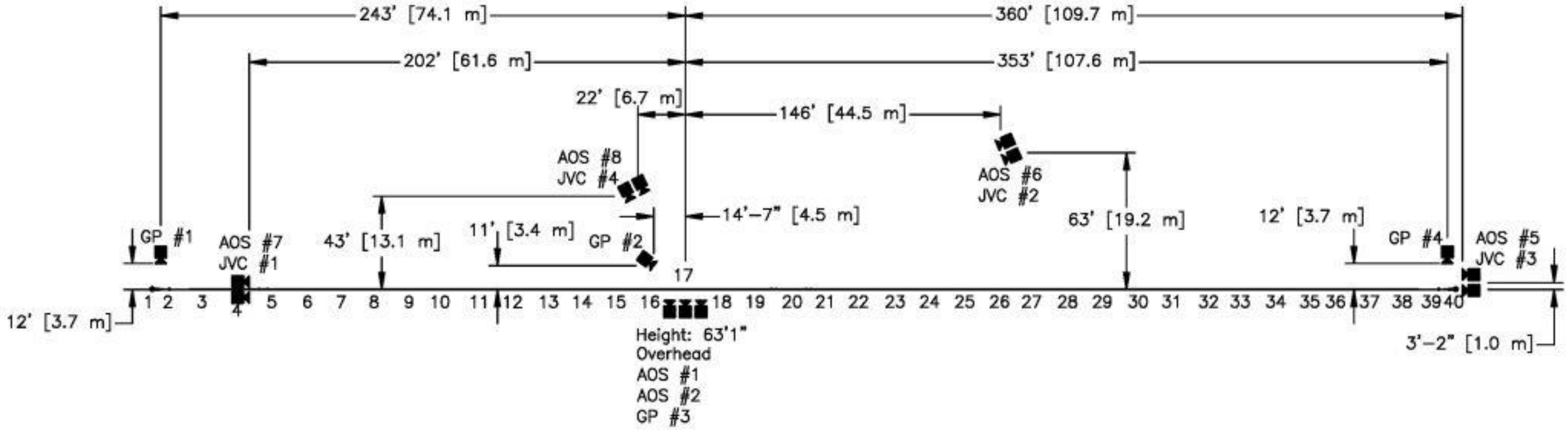
Two AOS Vitcam high-speed digital video cameras, one AOS S-VIT 1531 high-speed digital video camera, three AOS X-PRI high-speed digital video cameras, three JVC digital video cameras, two GoPro Hero 3+ digital video cameras, and two GoPro Hero 3 digital video cameras were utilized to film test no. MWP-3. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 13.

The high-speed videos were analyzed using ImageExpress MotionPlus and RedLake MotionScope software programs. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed videos. A Nikon D50 digital still camera was also used, to document pre- and post-test conditions for all tests.



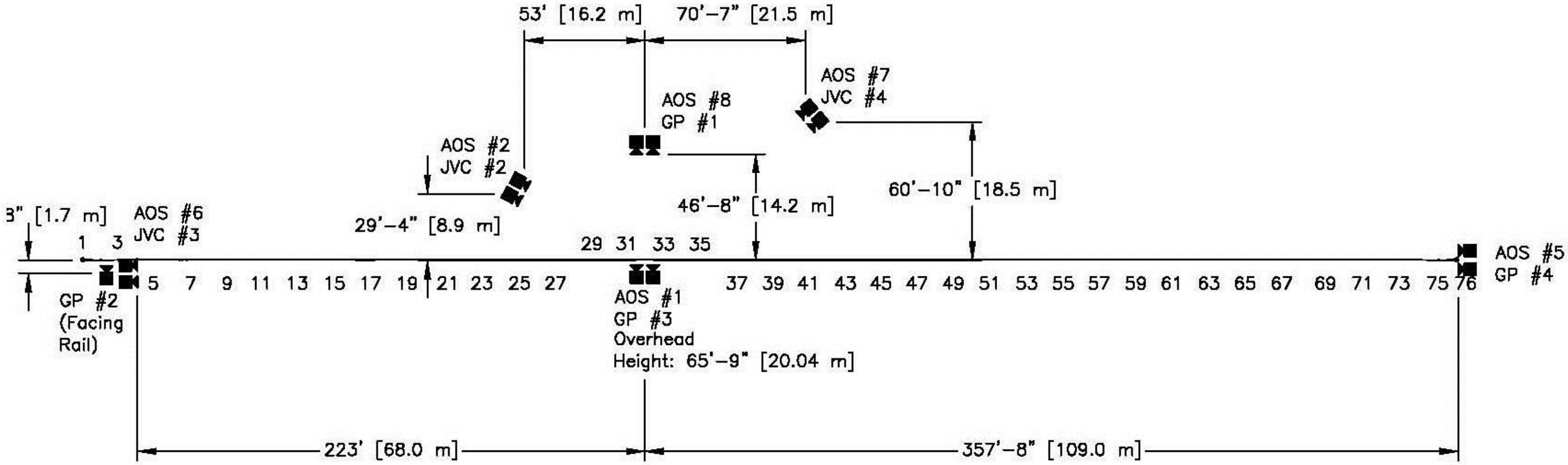
Camera No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-1	AOS Vitcam CTM	500	Kowa 8mm fixed	Fixed 8mm
AOS-2	AOS Vitcam CTM	500	Cosmicar 12.5mm fixed	12.5
AOS-3	AOS Vitcam CTM	500	Nikon Nikkor 20mm fixed	Fixed 20mm
AOS-5	AOS X-PRI Gigabit	500	Canon 17-102	75
AOS-6	AOS X-PRI Gigabit	500	Nikon Nikkor 28mm fixed	28mm
AOS-7	AOS X-PRI Gigabit	500	Minolta 50mm fixed	Fixed 50mm
AOS-8	AOS S-VIT 1531	500	Fujinon 50mm fixed	50mm
GP-1	GoPro Hero 3	120		
GP-2	GoPro Hero 3	120		
GP-3	GoPro Hero 3+	120		
GP-4	GoPro Hero 3+	120		
JVC-1	JVC – GZ-MC500 (Everio)	29.97		
JVC-2	JVC – GZ-MG27u (Everio)	29.97		
JVC-3	JVC – GZ-MG27u (Everio)	29.97		
JVC-4	JVC – GZ-MG27u (Everio)	29.97		

Figure 11. Camera Locations, Speeds, and Lens Settings, Test No. MWP-1



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-1	AOS VITcam CTM	500	Cosmicar 12.5mm fixed	
AOS-2	AOS VITcam CTM	500	Kowa 8mm fixed	
AOS-5	AOS X-PRI Gigabit	500	Sigma 24-135	100
AOS-6	AOS X-PRI Gigabit	500	Nikon 28-70	35
AOS-7	AOS X-PRI Gigabit	500	Sigma 28-70 Nikon	50
AOS-8	AOS S-VIT Gigabit 1531	500	Nikon 28mm	
GP-1	GoPro Hero 3	120		
GP-2	GoPro Hero 3	120		
GP-3	GoPro Hero 3+	120		
GP-4	GoPro Hero 3+	120		
JVC-1	JVC – GZ-MC500 (Everio)	29.97		
JVC-2	JVC – GZ-MG27u (Everio)	29.97		
JVC-3	JVC – GZ-MG27u (Everio)	29.97		
JVC-4	JVC – GZ-MG27u (Everio)	29.97		

Figure 12. Camera Locations, Speeds, and Lens Settings, Test No. MWP-2



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-1	AOS VITcam CTM	500	Cosmicar 12.5mm fixed	
AOS-2	AOS VITcam CTM	500	Sigma 28-70	28
AOS-5	AOS X-PRI Gigabit	500	Canon 17-102	102
AOS-6	AOS X-PRI Gigabit	500	Fujinon 50mm	
AOS-7	AOS X-PRI Gigabit	500	Nikkor 20mm	
AOS-8	AOS S-VIT Gigabit 1531	500	Nikkor 20mm	
GP-1	GoPro Hero 3	120		
GP-2	GoPro Hero 3	120		
GP-3	GoPro Hero 3+	120		
GP-4	GoPro Hero 3+	120		
JVC-2	JVC – GZ-MG27u (Everio)	29.97		
JVC-3	JVC – GZ-MG27u (Everio)	29.97		
JVC-4	JVC – GZ-MG27u (Everio)	29.97		

Figure 13. Camera Locations, Speeds, and Lens Settings, Test No. MWP-3

4 DESIGN DETAILS TEST NO. MWP-1

The non-proprietary four-cable median barrier system evaluated in test no. MWP-1 is detailed in Figures 14 through 37. The test installation was constructed with a total length of 608 ft (185.3 m) and was placed on the front slope break point of a 6H:1V V-ditch. The cable barrier system was comprised of several distinct components: (1) high-tension cables or wire ropes, (2) cable splices, (3) steel support posts, (4) cable-to-post attachment brackets, (5) breakaway end terminals, and (6) reinforced concrete foundations. Photographs of the test installation are shown in Figure 38. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

Four ¾-in. (19-mm) diameter, Class A galvanized 3x7 (pre-stretched) wire ropes were utilized for the longitudinal cables. The barrier utilized a consistent 16-in. (406-mm) cable spacing, as the cables were placed at heights of 13¾ in. (349 mm), 22½ in. (572 mm), 31¼ in. (794 mm), and 40 in. (1,016 mm) above the ground surface. The cables were numbered 1 through 4 going from the bottom cable to the top cable. Cable nos. 1 and 3 were attached to the impact side of each post, while cable no. 2 was attached to the non-impact side of each post, as shown in Figure 28. Cable no. 4 resided within the V-notch cut into the top of each post.

MASH requires that cable barrier systems be tested with cable tensions set to the recommended tension at 100 degrees Fahrenheit. Utilizing a cable tensioning chart developed as a function of ambient air temperature for use when installing the barrier system, as shown in Table 3, the cables were tensioned to a pre-load of 2,500 lb (11.1 kN). Each of the four wire ropes contained a splice in the impact region, between post nos. 19 and 22, as shown in Figure 15. Additionally, a load cell was spliced into each wire rope upstream from the point of impact, between post nos. 4 and 5, as shown in Figure 18. Details for the load cells, threaded rods, turnbuckles, end fittings, and rod couplers are provided in Figure 19.

Table 3. Pre-Stretched Cable Tension Chart

Ambient Air Temperature (Degrees Fahrenheit)	Cable Tension (lb)
110	2240
100	2500
90	2760
80	3021
70	3281
60	3541
50	3801
40	4062
30	4322
20	4582
10	4842
0	5102
-10	5363
-20	5623
-30	5883
-40	6143

The cables were supported by 36 line posts and anchored at the upstream and downstream ends with breakaway end terminals. Posts nos. 3 through 38 were Midwest Weak Posts (MWPs) [8] installed in soil measuring 83 in. (2,108 mm) in length. The MWPs were fabricated from bent 7-gauge (4.6-mm) sheet steel to a 3-in. x 1¾-in. (76-mm x 44-mm) cross section, as shown in Figures 28 through 31. The post spacing between adjacent MWPs was 16 ft (4.9 m).

A breakaway cable end terminal system was utilized at each end of the cable barrier system, as shown in Figures 16, 17, and 20 through 23. Post nos. 1 and 40 consisted of a 4-cable anchor bracket assembly that was anchored to reinforced concrete foundations at both ends of the system. Post nos. 2 and 39 were slip-base support posts anchored to reinforced concrete foundations with attached hanger hardware, as shown in Figures 24 through 27. The spacing between the cable anchor bracket assembly and the adjacent slip-base support posts was 8 ft (2.4 m).

Cables 1 through 3 were attached to the MWPs using tabbed brackets [5]. These brackets were fabricated from 12-gauge (2.7-mm) steel and bolted to the post utilizing a $^{5}/_{16}$-in. (8-mm) bolt. The top cable was secured within the V-notch on top of each post with a $^{3}/_{16}$-in. (5-mm) diameter brass keeper rod [7]. Details for the cable-to-post attachment brackets and brass keeper rods can be found in Figures 28 through 34.

For MASH test designation no. 3-17, the barrier was placed on the front slope of a 6H:1V V-ditch to maximize the propensity for the front end of a 1500A vehicle to penetrate between vertically adjacent cables. A 400-ft (121.9-m) long simulated V-ditch was constructed using an overall width of 30 ft (9.1 m) in combination with 6H:1V side slopes. Utilizing the individual cable heights and the front end geometry of the 2006 Ford Taurus, it was determined that the front bumper was located directly between cables 1 and 2 on level terrain, as shown in Figure 39. All of the cables were spaced evenly in the vertical direction, so the vehicle had the greatest propensity for penetration with the barrier placed on level terrain. Therefore, the four-cable median barrier system was placed at the front slope break point of the 6H:1V V-ditch, as shown in Figure 14.

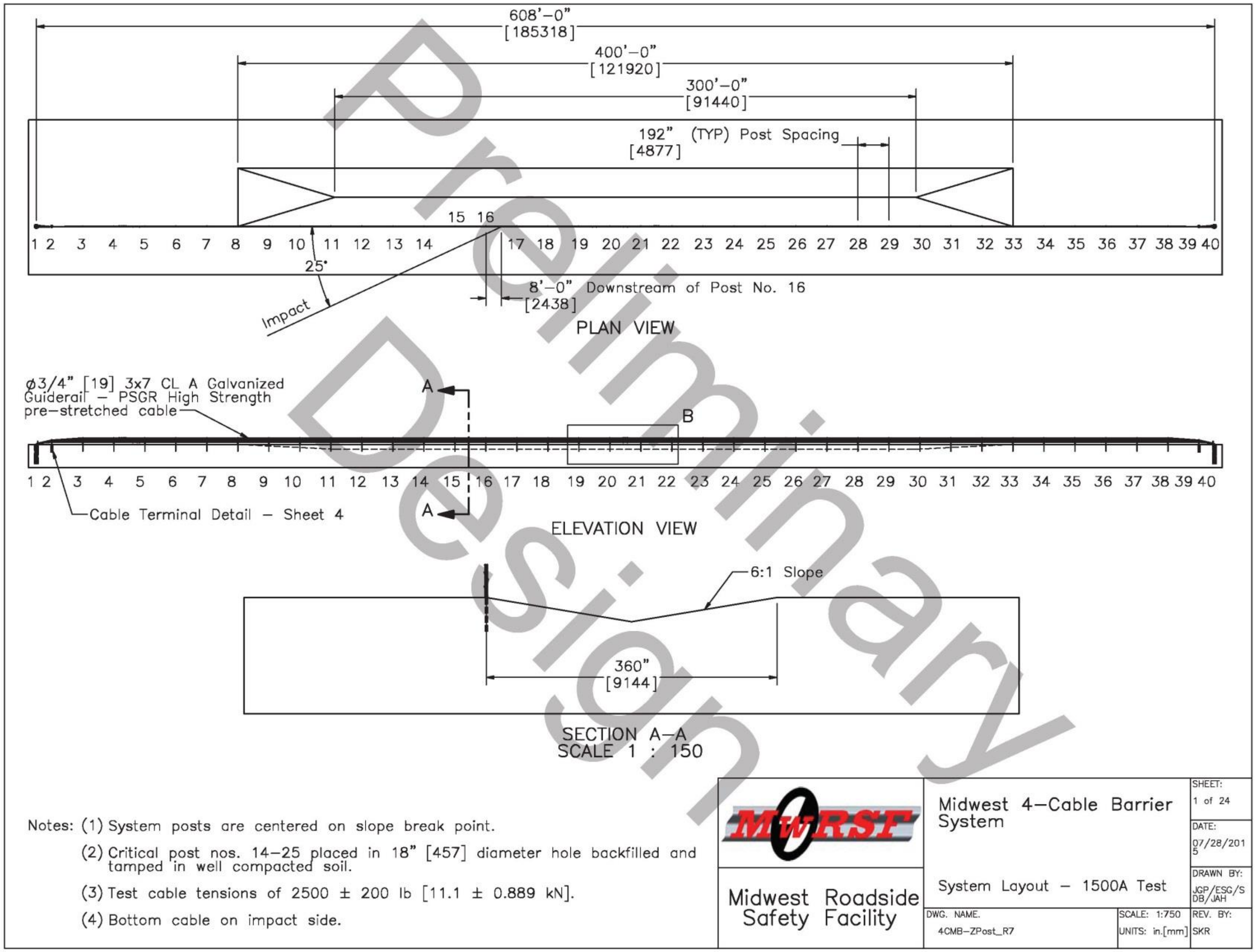


Figure 14. Test Installation Layout, Test No. MWP-1

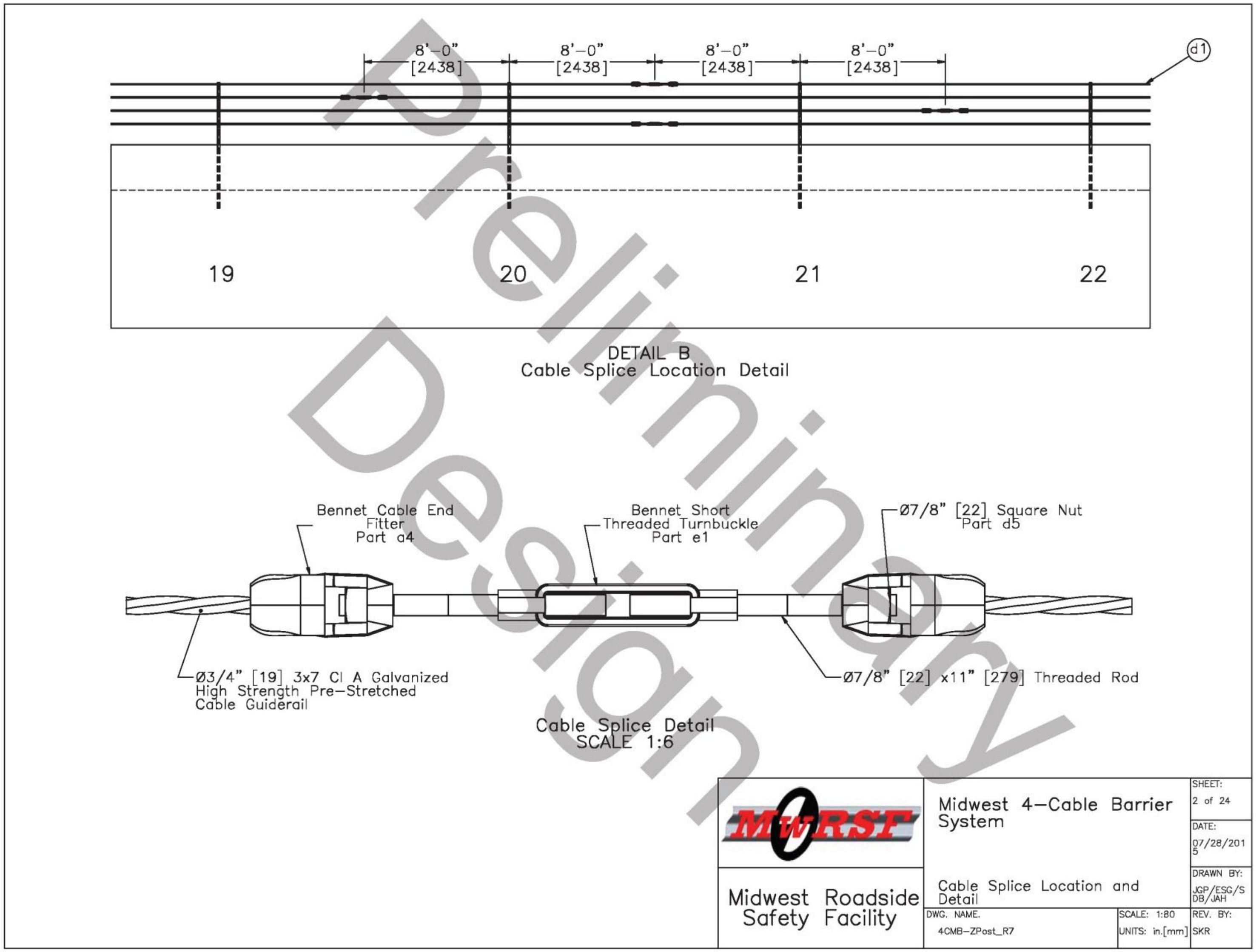


Figure 15. Cable Splice Location and Detail, Test No. MWP-1

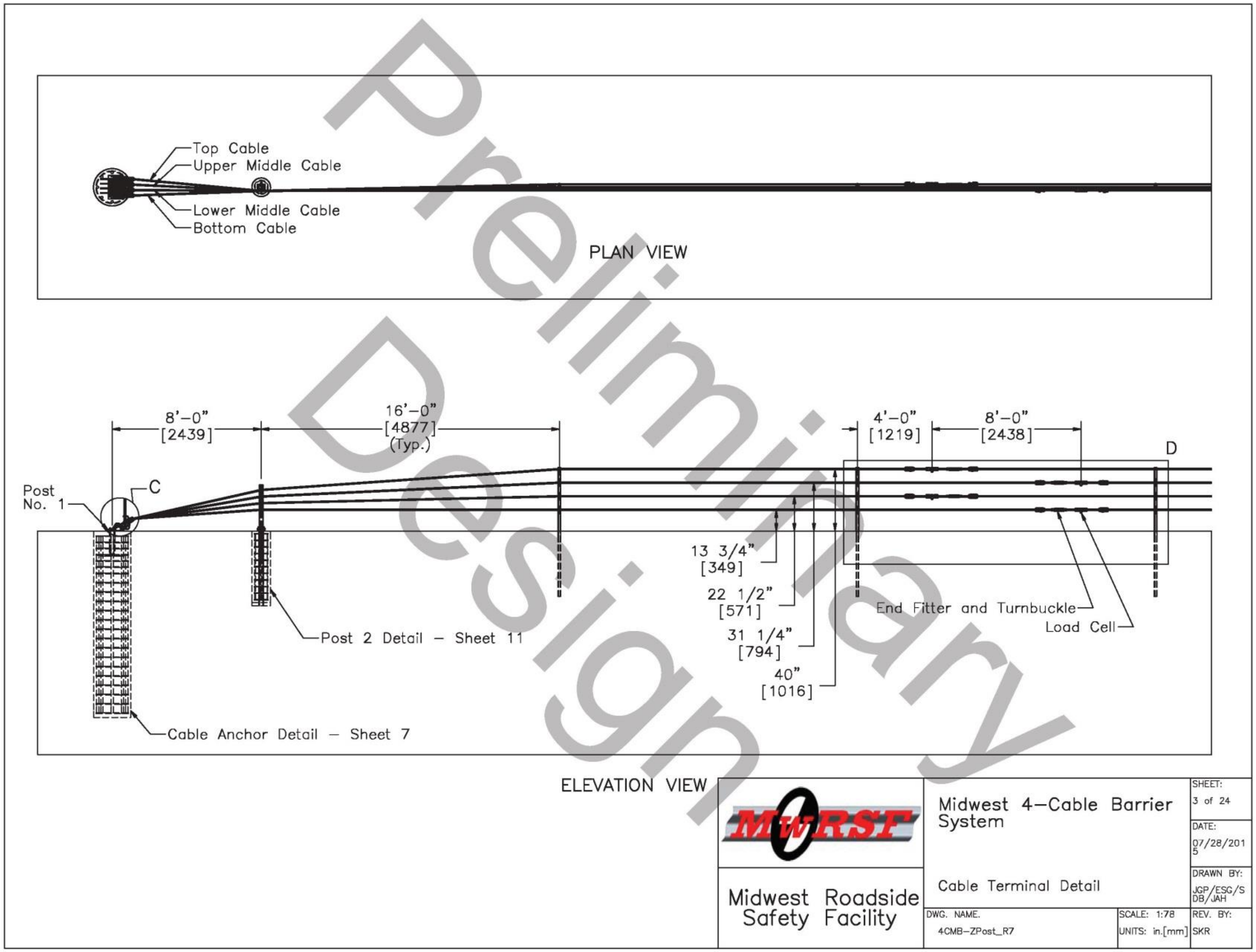


Figure 16. Cable Terminal Detail, Test No. MWP-1

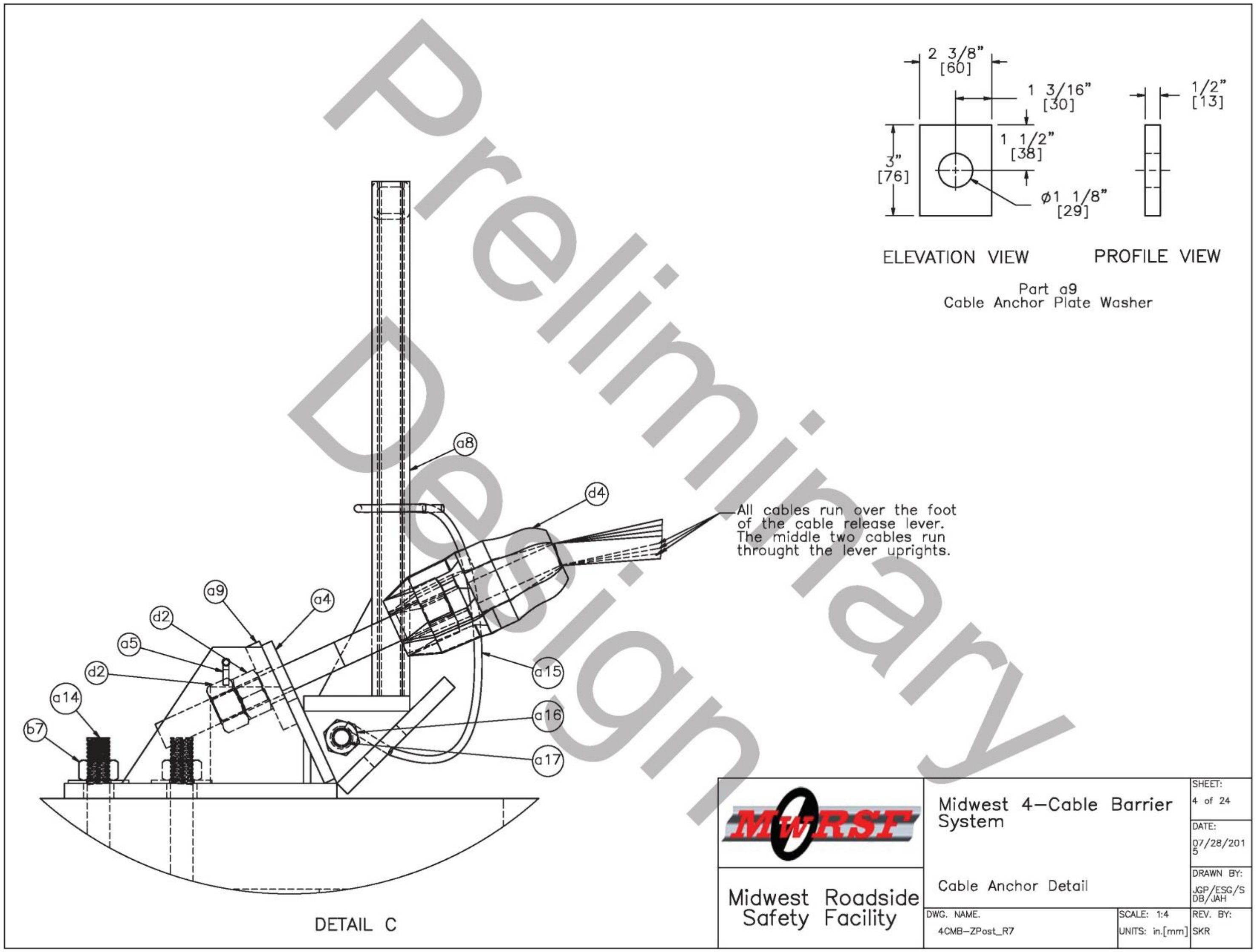


Figure 17. Cable Anchor Detail, Test No. MWP-1

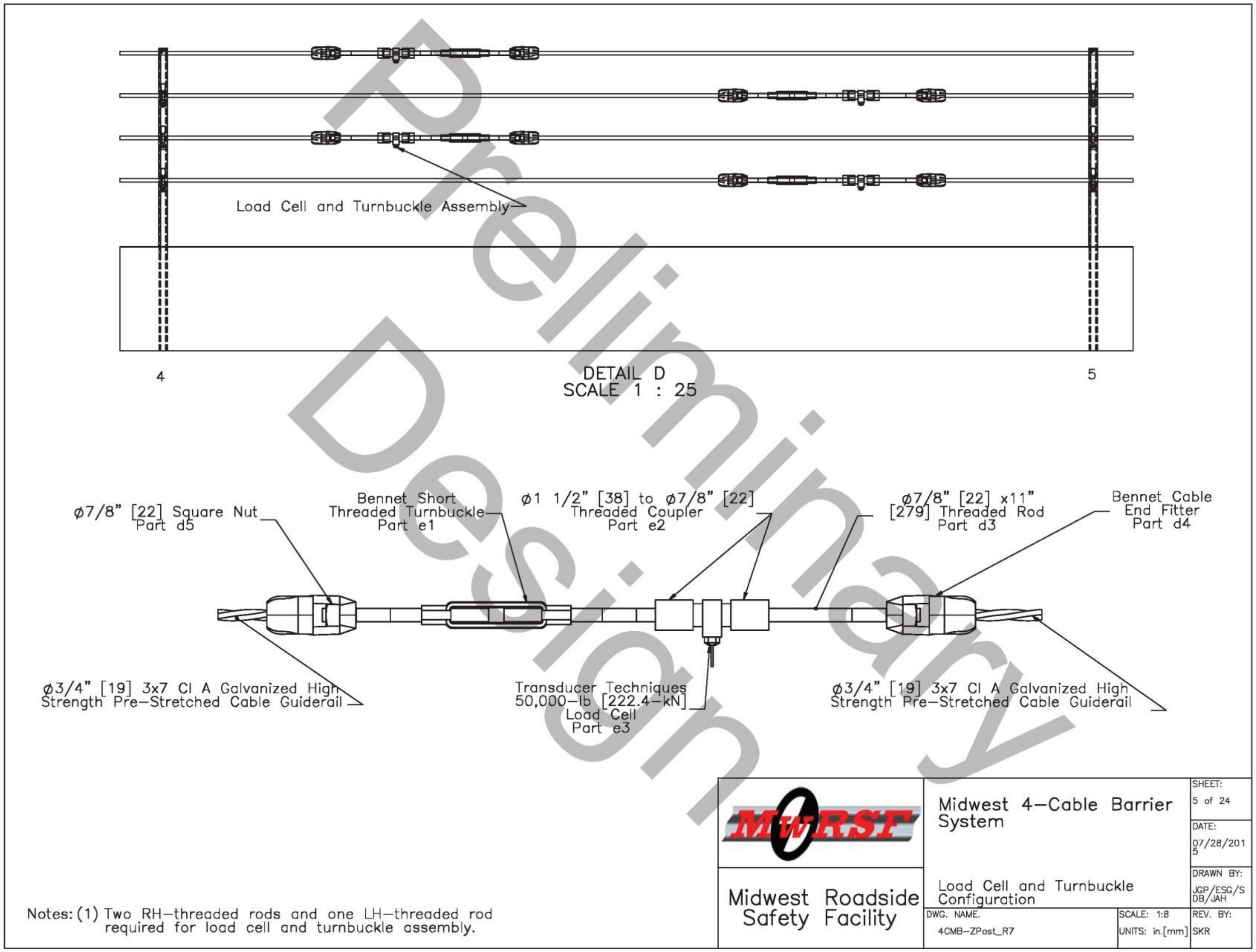


Figure 18. Load Cell and Turnbuckle Configuration, Test No. MWP-1

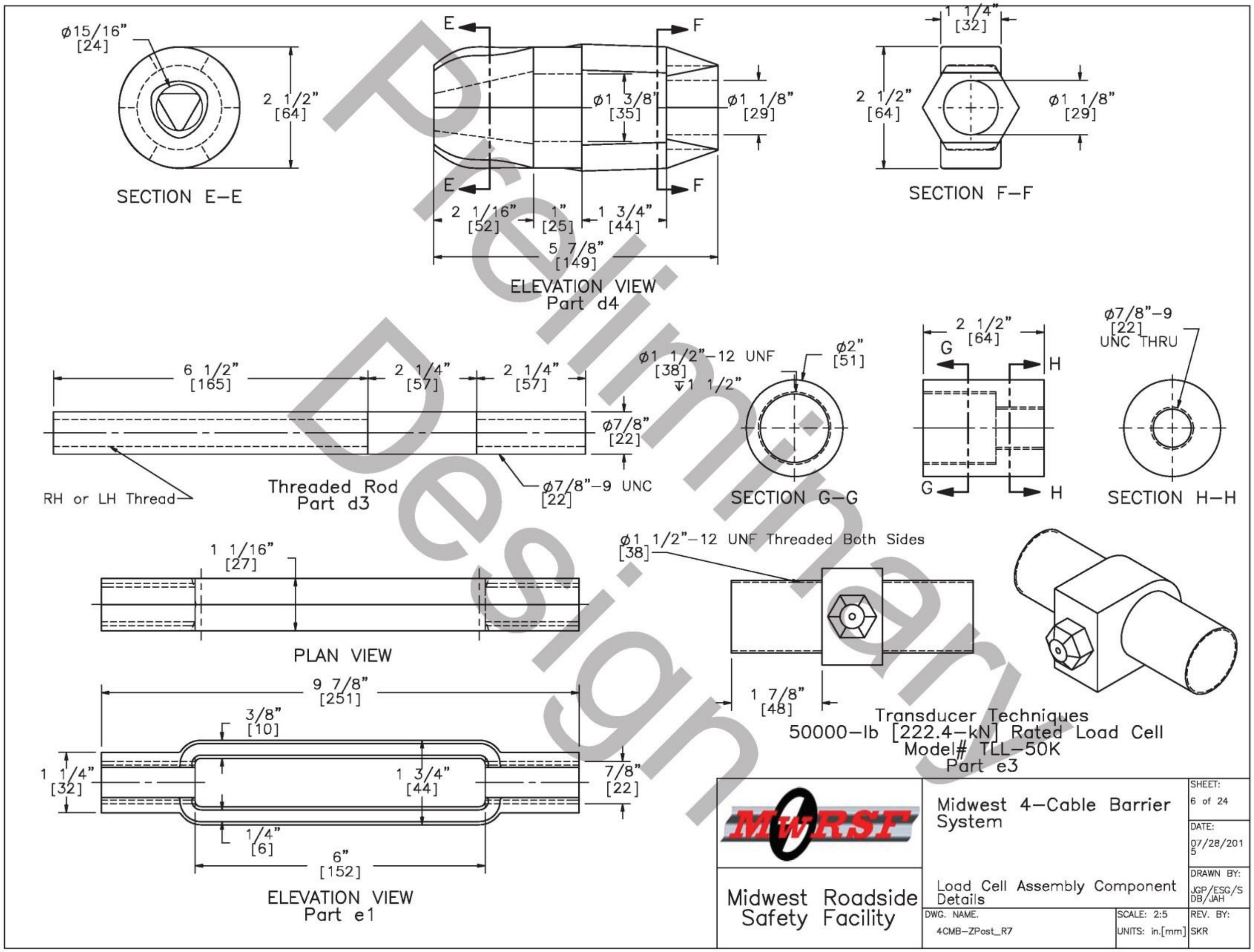


Figure 19. Load Cell Assembly Component Details, Test No. MWP-1

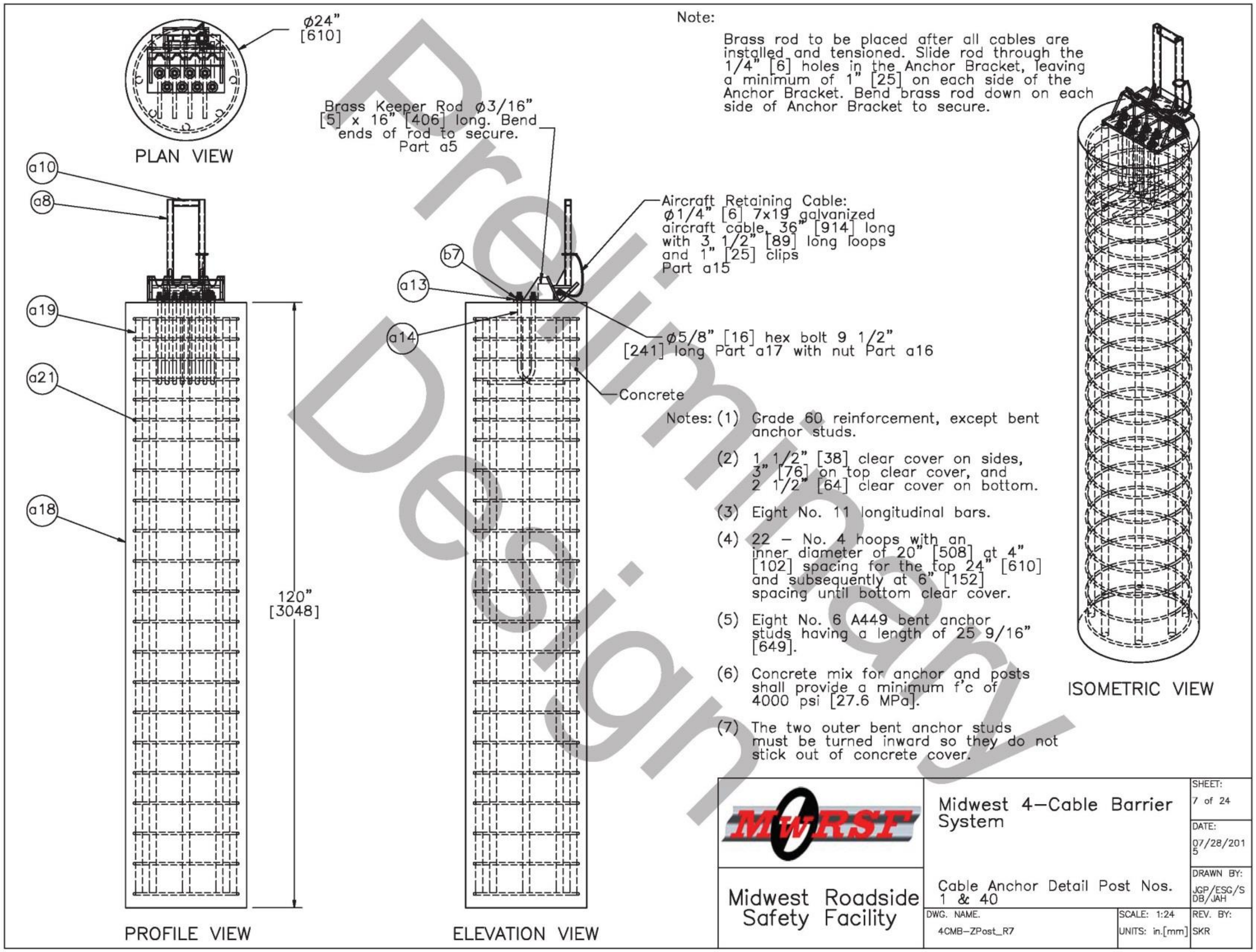


Figure 20. Cable Anchor Detail Post Nos. 1 and 40, Test No. MWP-1

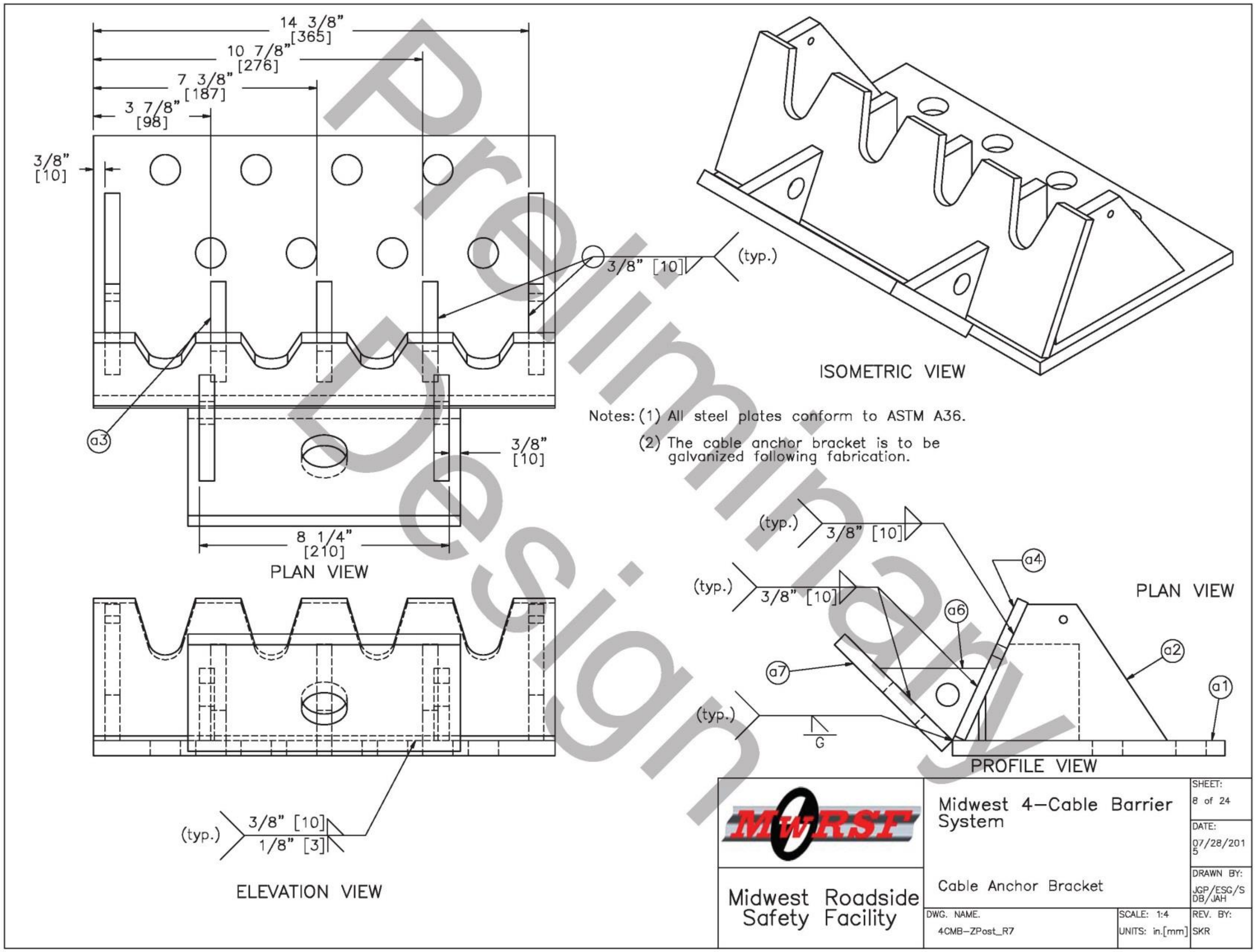


Figure 21. Cable Anchor Bracket, Test No. MWP-1

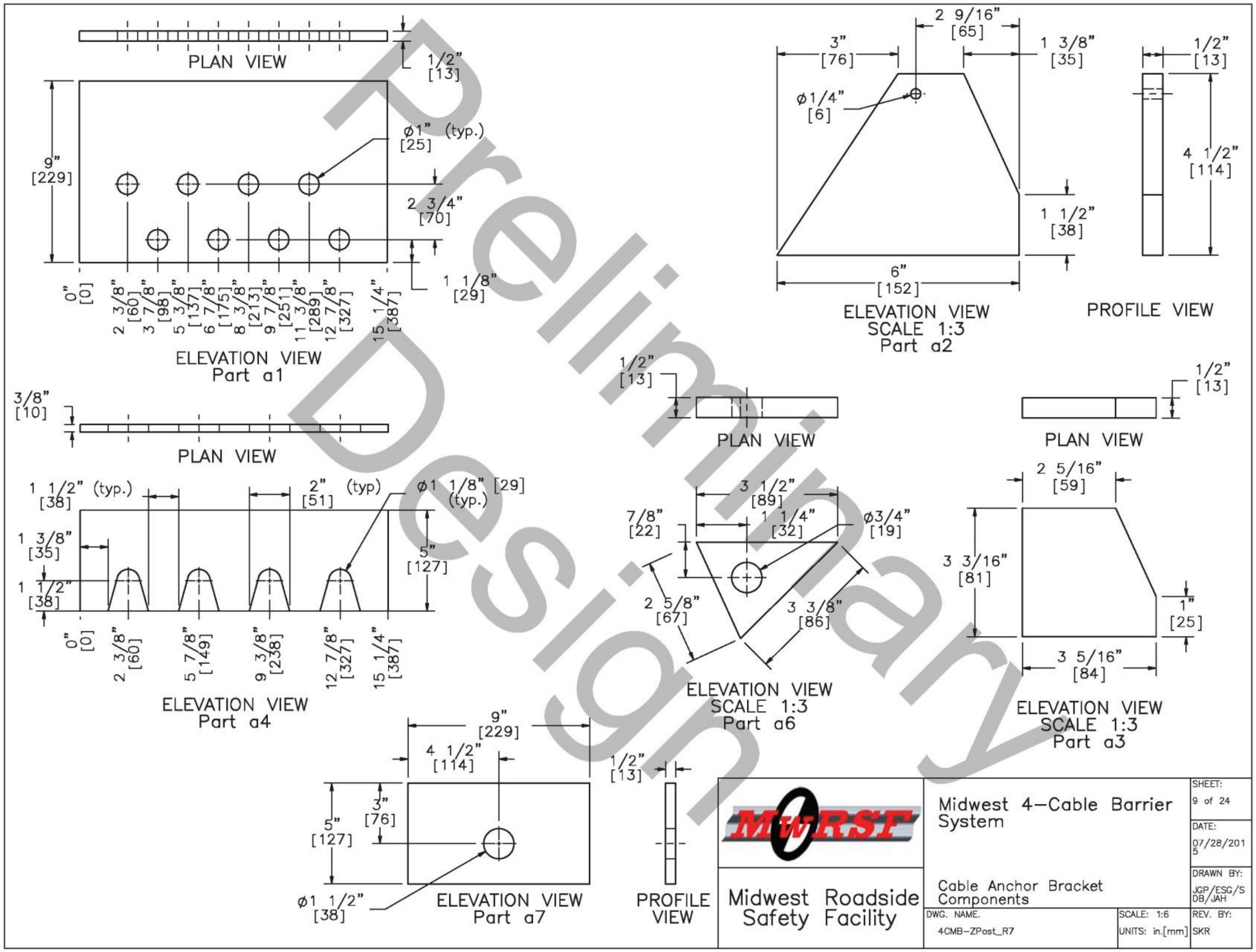


Figure 22. Cable Anchor Bracket Components, Test No. MWP-1

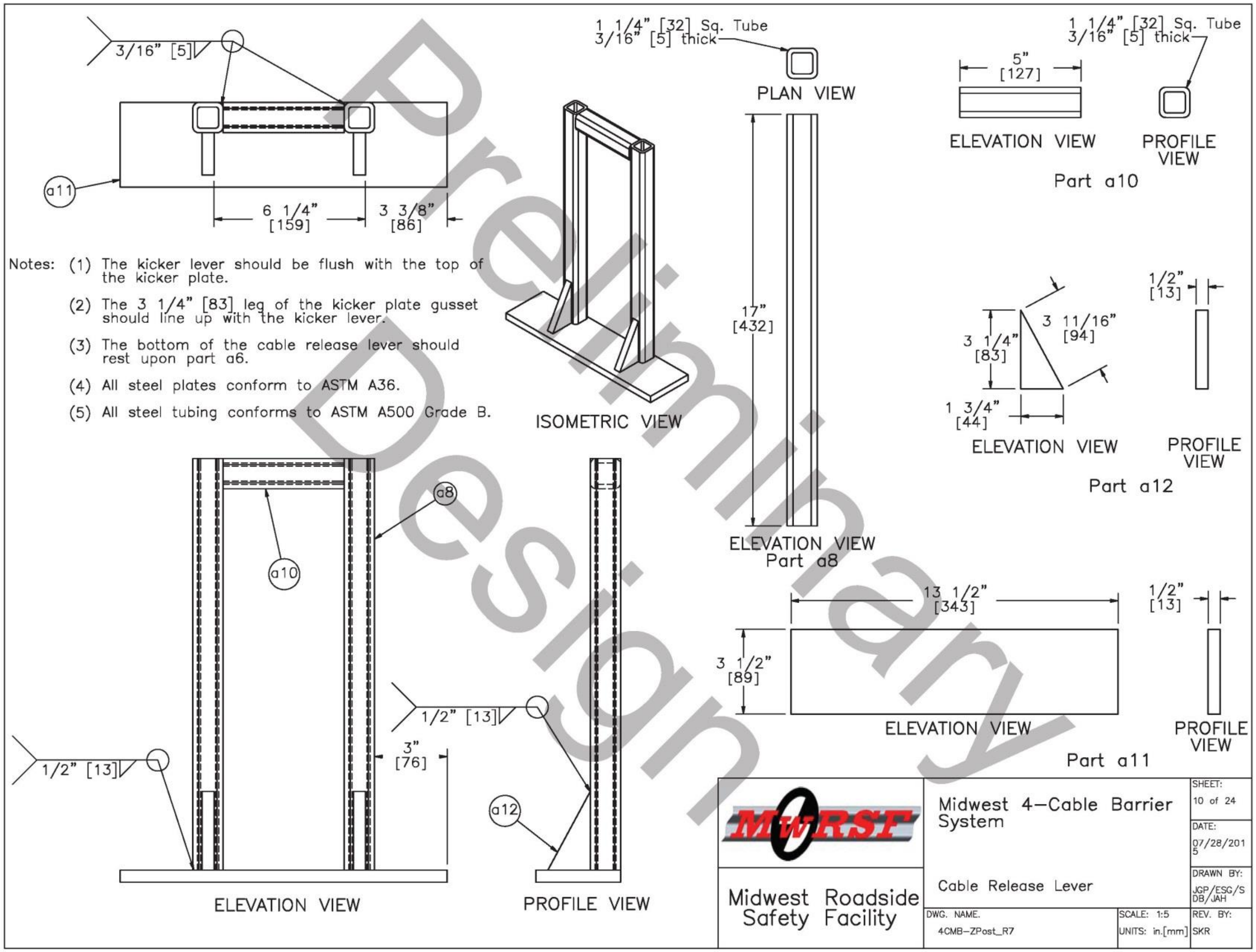


Figure 23. Cable Release Lever, Test No. MWP-1

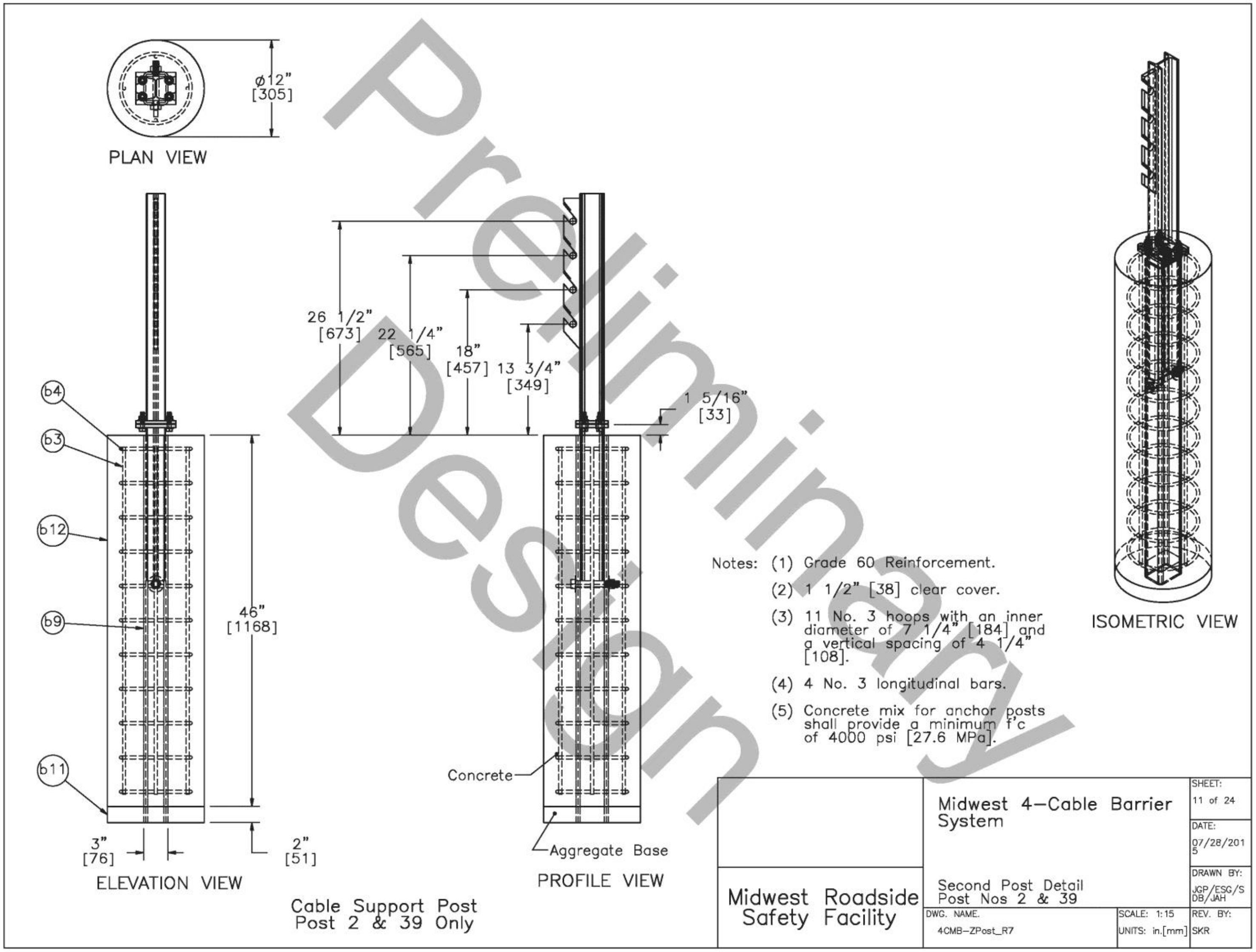


Figure 24. Second Post Details, Post Nos. 2 and 39, Test No. MWP-1

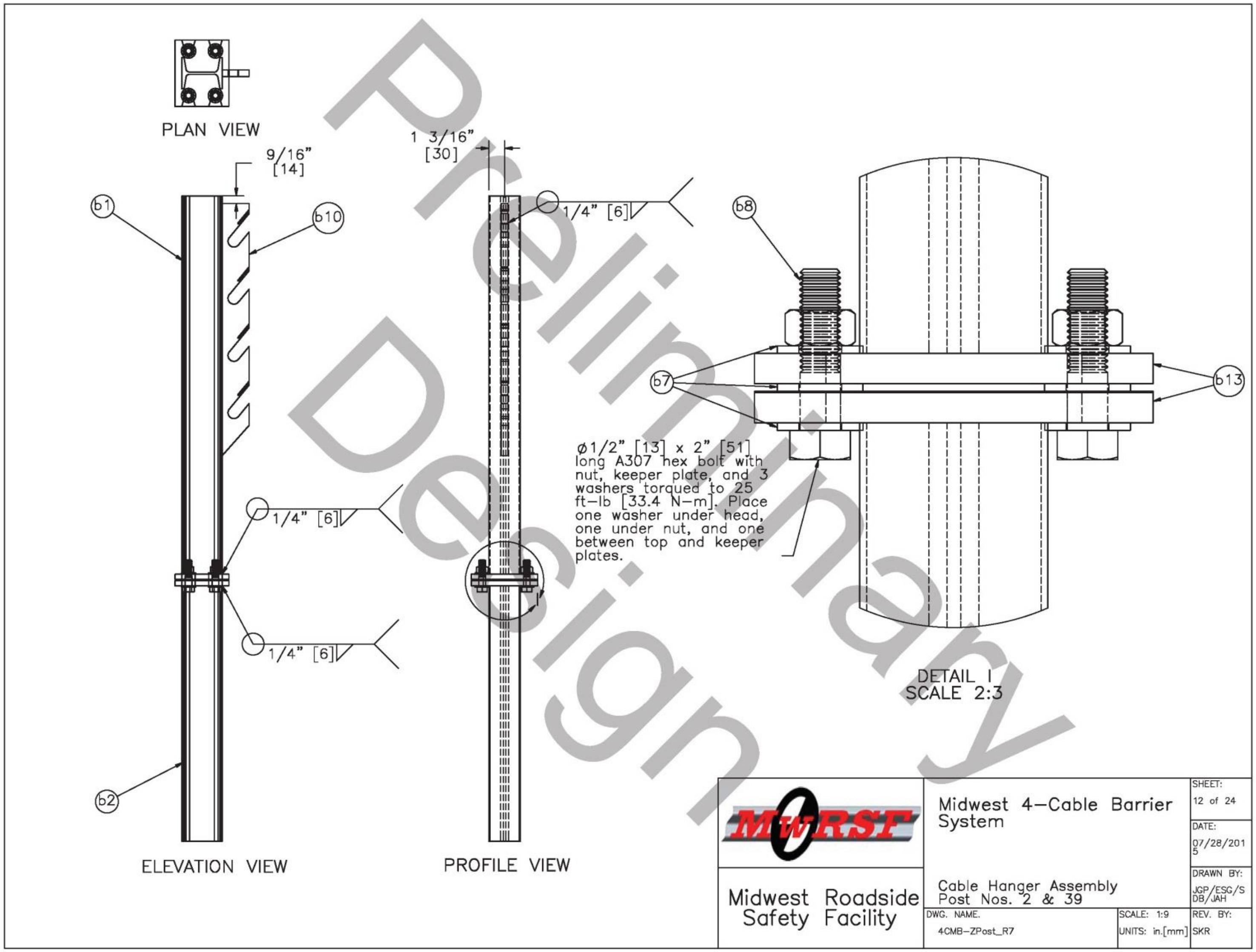


Figure 25. Cable Hanger Assembly, Post Nos. 2 and 39, Test No. MWP-1

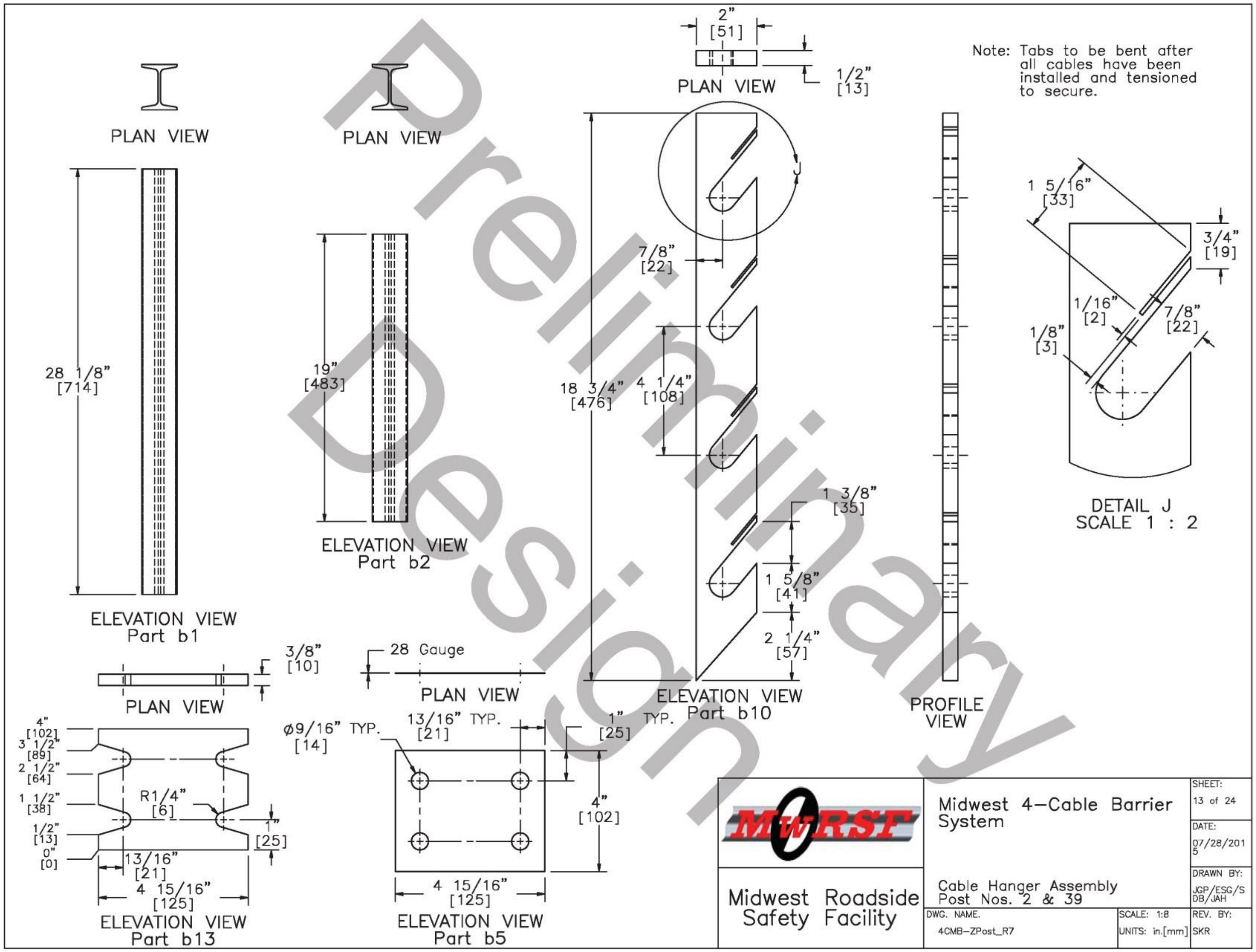


Figure 26. Cable Hanger Assembly, Post Nos. 2 and 39, Test No. MWP-1

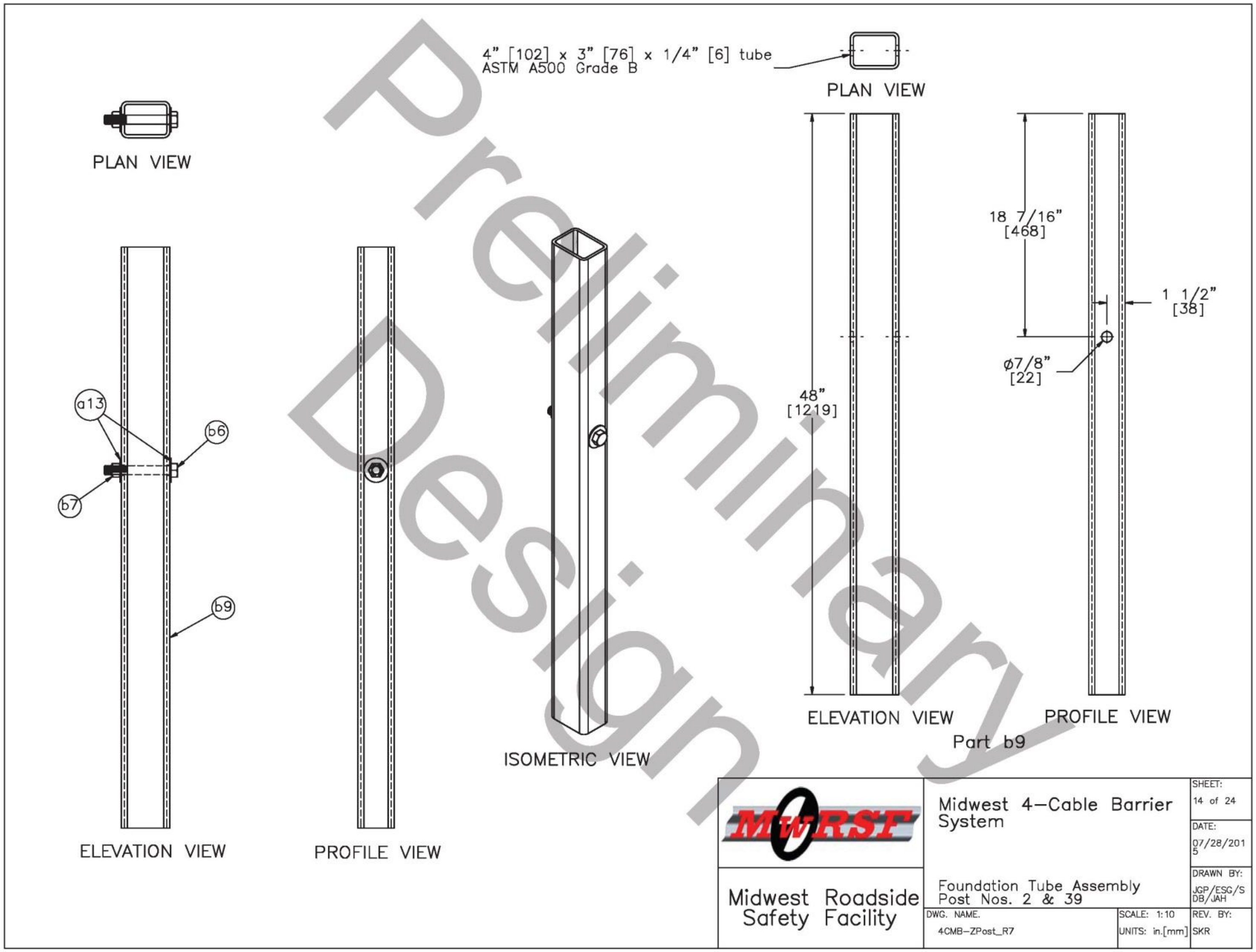


Figure 27. Foundation Tube Assembly, Post Nos. 2 and 39, Test No. MWP-1

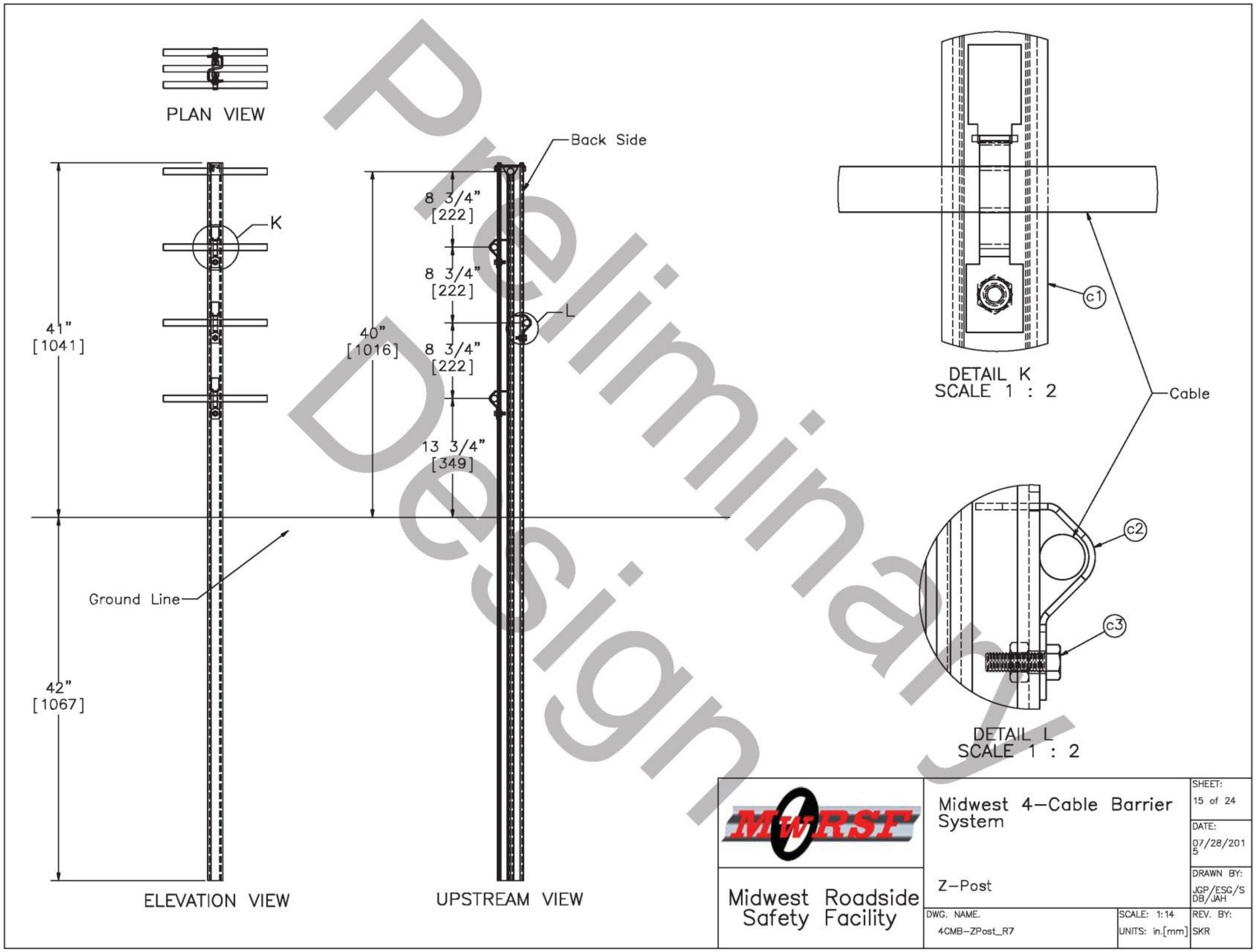


Figure 28. Z-Post Details, Test No. MWP-1

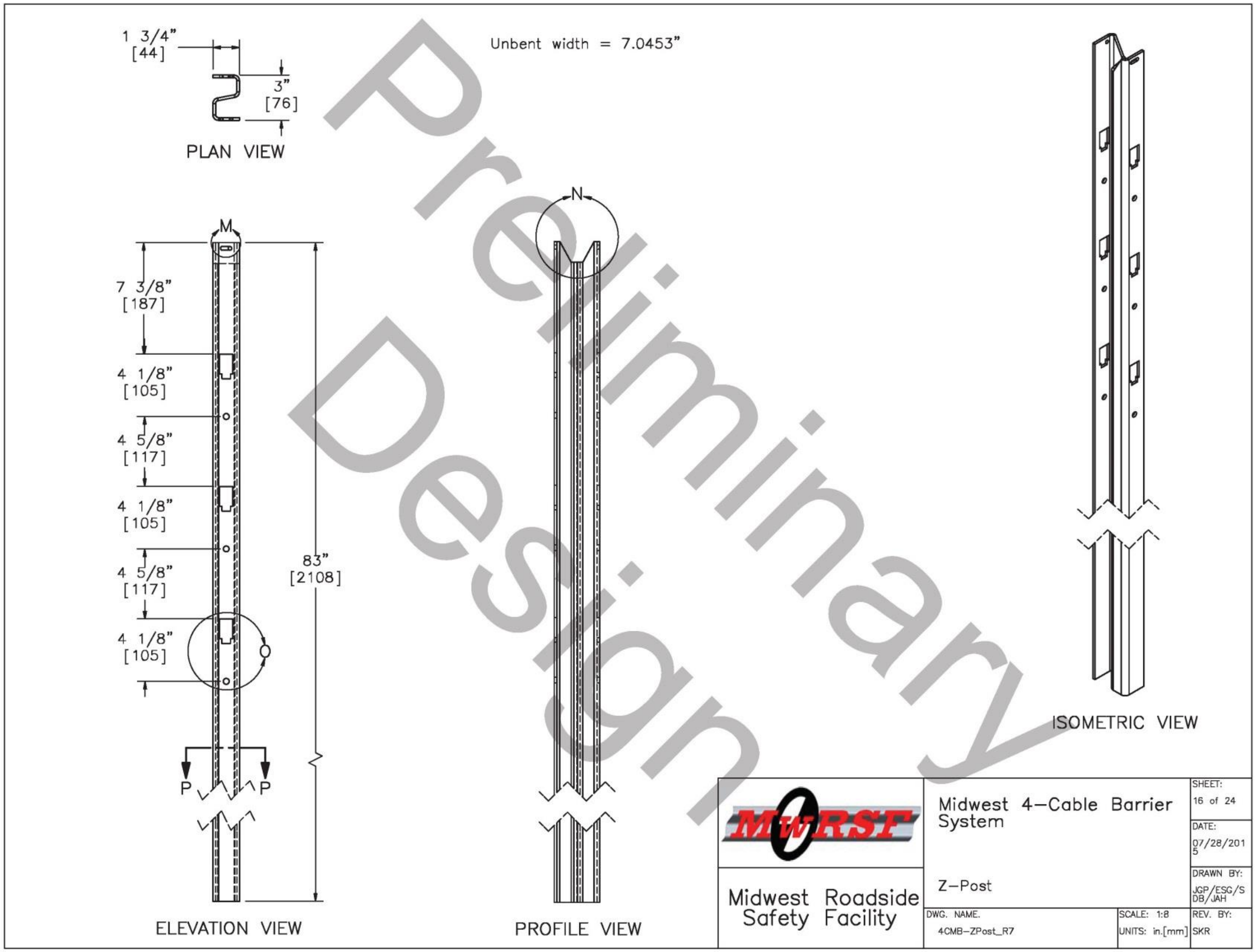


Figure 29. Z-Post Details, Test No. MWP-1

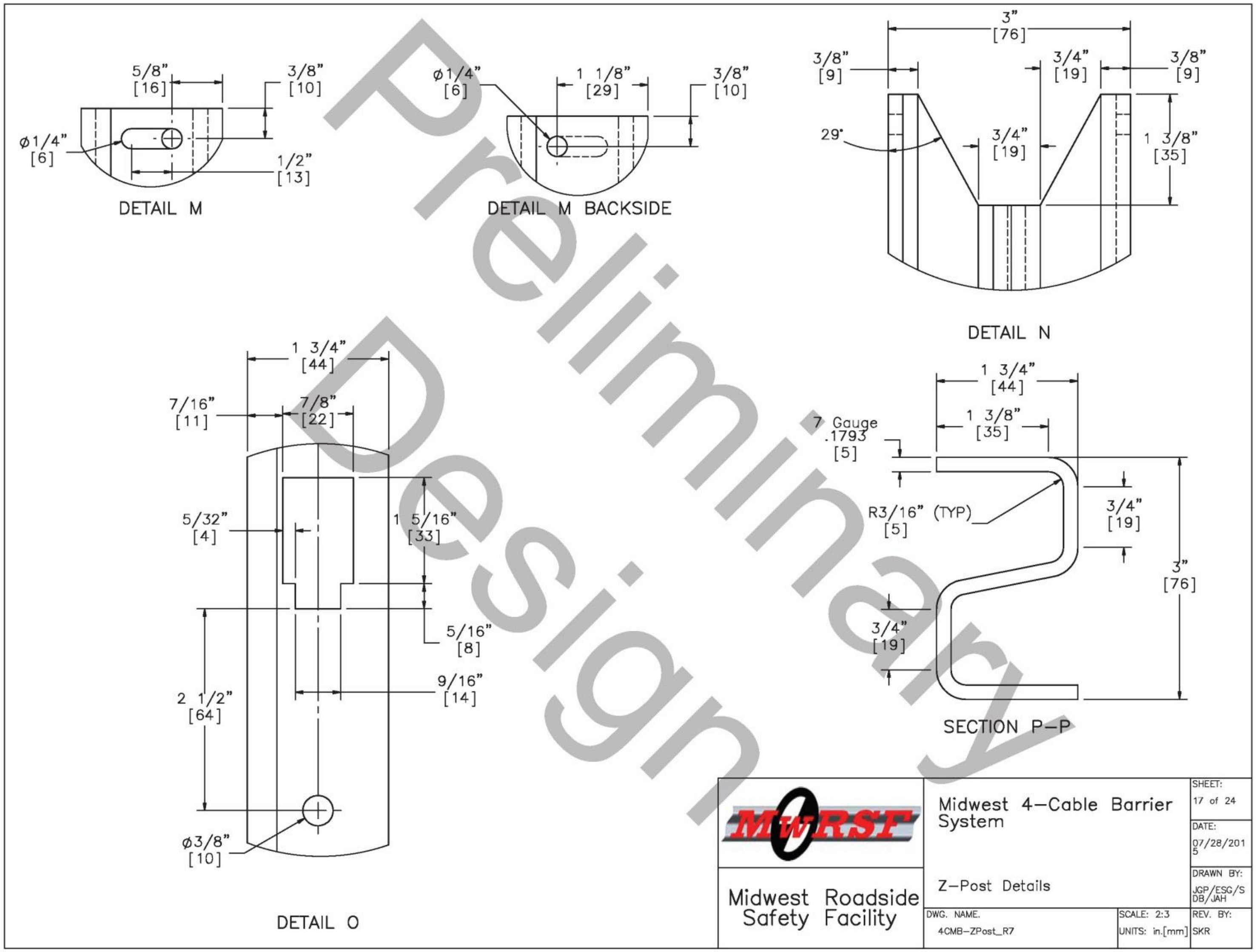


Figure 30. Z-Post Details, Test No. MWP-1

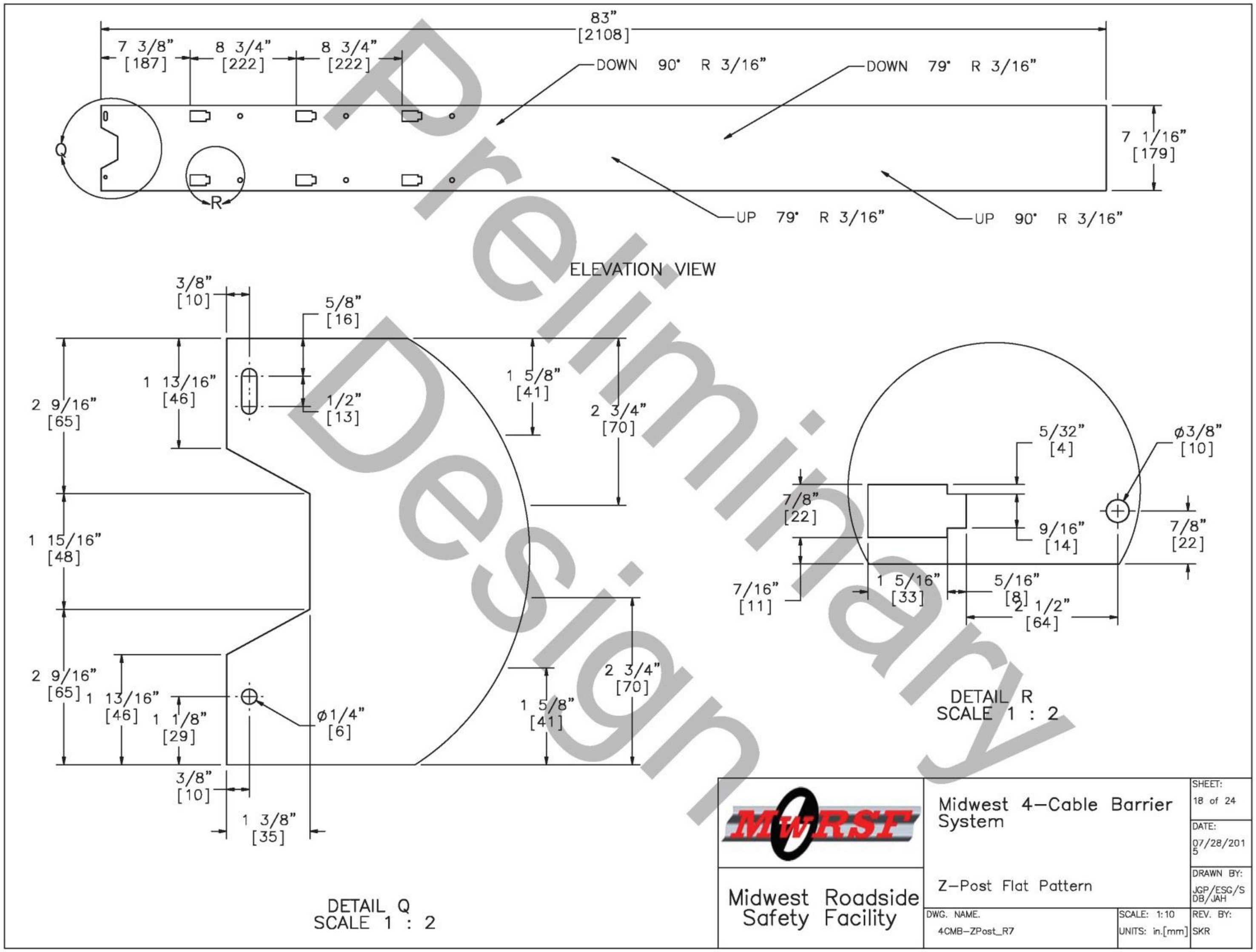


Figure 31. Z-Post Details, Flat Pattern, Test No. MWP-1

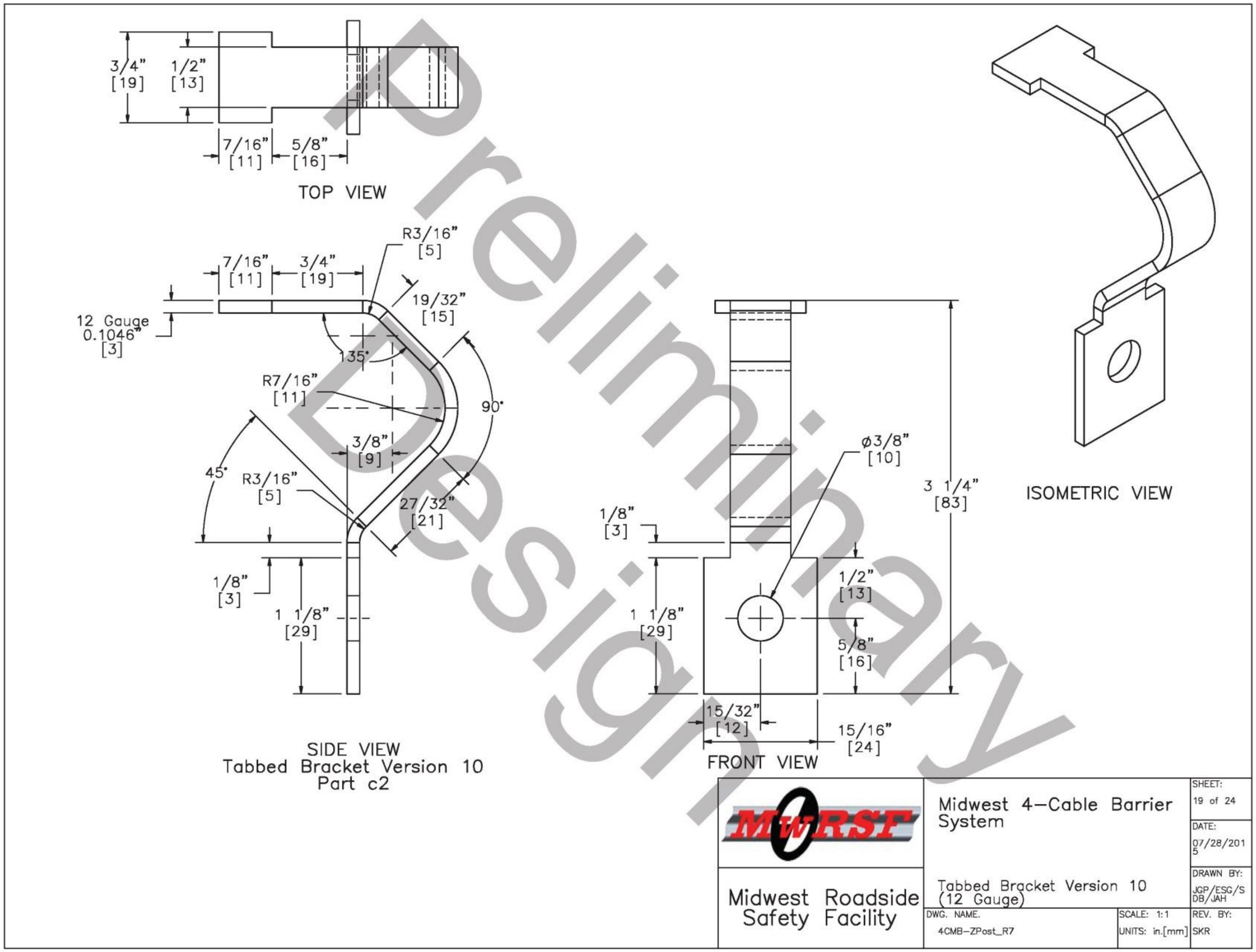
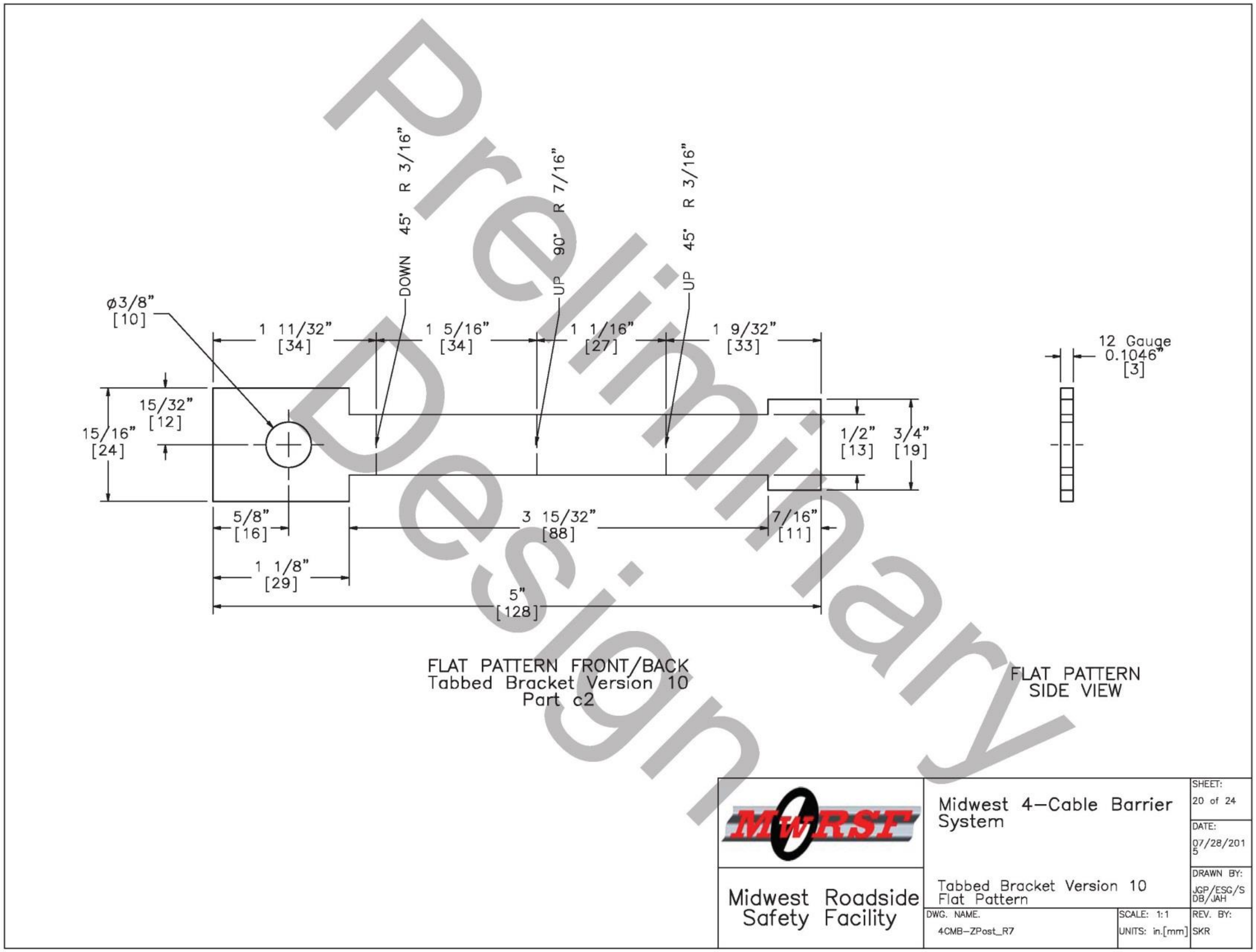


Figure 32. Tabbed Bracket Details, 12-Gauge, Test No. MWP-1



Preliminary Design

Figure 33. Tabbed Bracket Details, Flat Pattern, Test No. MWP-1

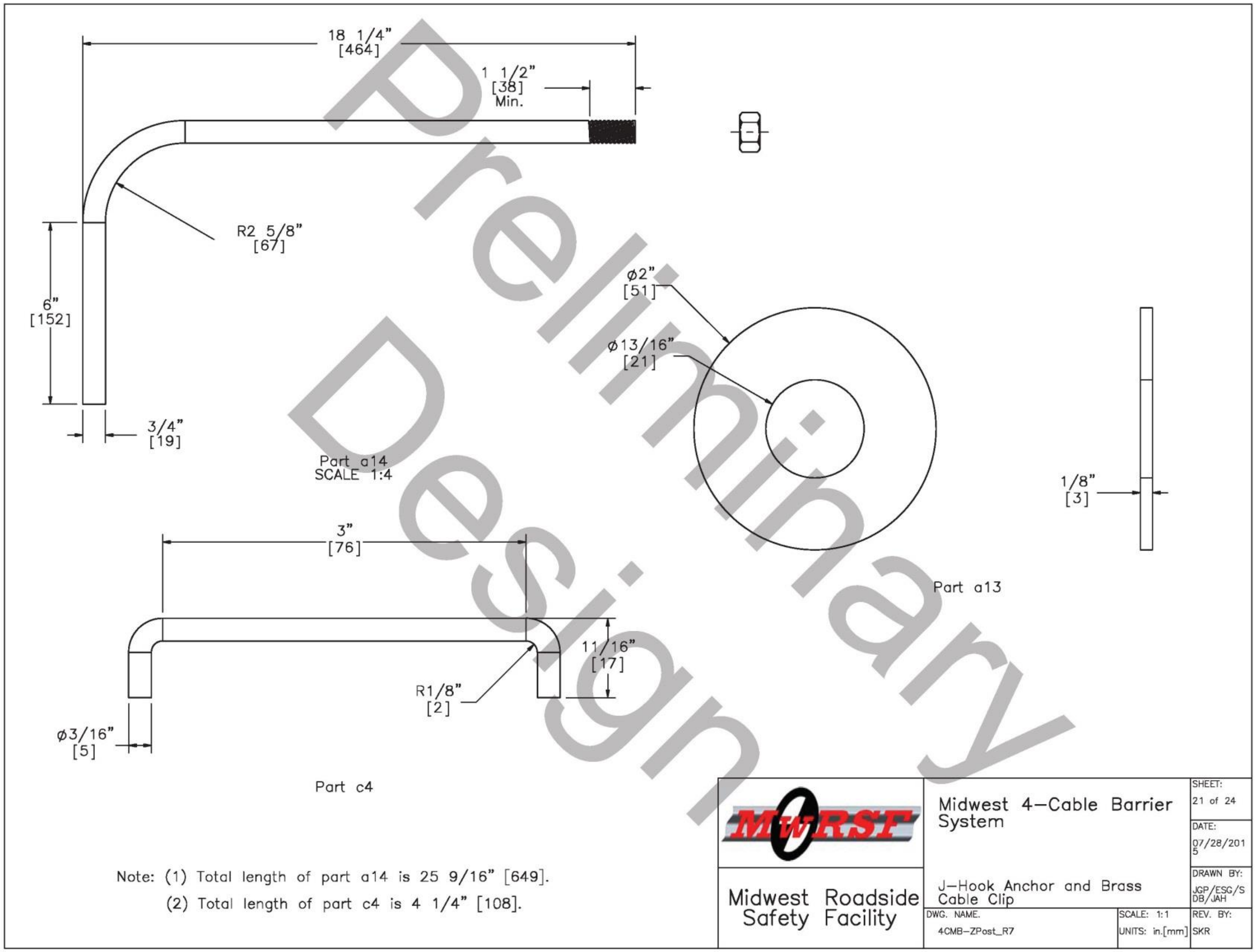


Figure 34. J-Hook Anchor and Brass Clips, Test No. MWP-1

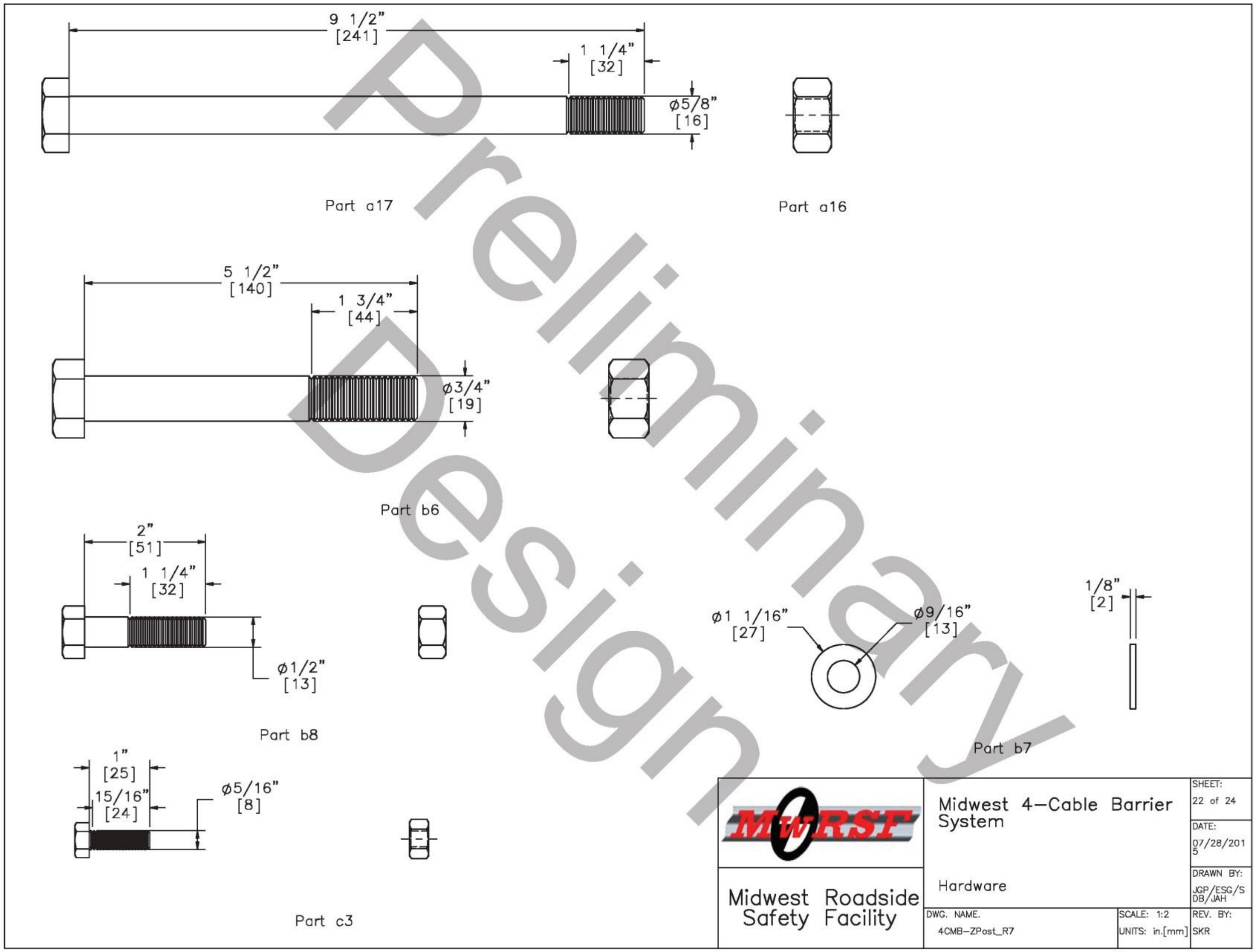


Figure 35. Hardware Details, Test No. MWP-1

Item No.	QTY.	Description	Material Specification
a1	2	Cable Anchor Base Plate	ASTM A36
a2	4	Exterior Cable Plate Gusset	ASTM A36
a3	6	Interior Cable Plate Gusset	ASTM A36
a4	2	Anchor Bracket Plate	ASTM A36
a5	2	3/16" [5] Dia. Brass Keeper Rod, 16" [406] long	Brass
a6	4	Release Gusset	A36 Steel
a7	2	Release Lever Plate	A36 Steel
a8	4	1.25x1.25x0.1875" [32x32x5] TS CT Kicker Lever Tube	ASTM A500 Gr. B
a9	8	CMB High Tension Anchor Plate Washer	ASTM A36
a10	2	1.25x1.25x0.1875" [32x32x5] TS CT Kicker Lever Connecting Tube	ASTM A 500 Gr. B
a11	2	3x10x0.5" [76x254x13] Kicker Plate	ASTM A36
a12	4	CT kicker – gusset	ASTM A36
a13	20	3/4" [19] Dia. Flat Washer	ASTM F844
a14	16	3/4" [19] Dia. UNC J–Hook Anchor and Hex Nut	J–Hook ASTM A449/Nut ASTM A563 DH
a15	2	1/4" [6] Dia. Aircraft Retaining Cable, 36" [914] long	7x19 Galv.
a16	2	5/8" [16] Dia. Heavy Hex Nut	ASTM A563C
a17	2	5/8" [16] Dia. UNC, 9 1/2" [241] Long Hex Bolt	ASTM A449 or SAE J429 Gr. 5
a18	2	24" [610] Dia. Concrete Anchor, 120" [3048] long	4,000 psi f'c
a19	16	#11 Straight Rebar, 114" [2896] long	Grade 60
a20	44	#4 Anchor Hoop Rebar with 21" [533] Dia.	Grade 60
b1	2	S3x5.7 [S76x8.5] Post by 28 1/8" [714]	ASTM A572 GR50–07, ASTM A709 GR50–09A, ASTM A992–06A
b2	2	S3x5.7 [S76x8.5] Post by 19" [483]	ASTM A572 GR50–07, ASTM A709 GR50–09A, ASTM A992–06A
b3	8	#3 Straight Rebar, 43" [1092] long	Grade 60
b4	22	7 1/4" [184] Dia. No. 3 Hoop Reinforcement	Grade 60
b5	2	2nd Post Keeper Plate, 28 Gauge	ASTM A36
b6	2	3/4" [19] Dia. UNC, 5 1/2" [140] Long Hex Bolt and Nut	Bolt ASTM A307 Gr. A/Nut ASTM A563A
b7	24	1/2" [13] Dia. Washer with 1 1/16" [27] OD	ASTM F844
b8	8	1/2" [13] Dia. UNC, 2" [51] long Hex Bolt and Nut	Bolt ASTM A307 Gr. A/Nut ASTM A563A
b9	2	4x3x1/4" [102x76x6] Foundation Tube, 48" [1168] long	ASTM A500 Grade B
b10	2	2nd Post Cable Hanger	ASTM A36
b11	2	2nd Post Anchor Aggregate 12 in, Depth	–
b12	2	12" Dia. 2nd Post Concrete Anchor, 46" long	4,000 psi f'c
b13	4	2nd Post Base Plate	ASTM A36

Midwest Roadside Safety Facility

Midwest 4–Cable Barrier System

Bill of Materials

SHEET: 23 of 24
DATE: 07/28/2015
DRAWN BY: JGP/ESG/SDB/JAH
DWG. NAME. 4CMB–ZPost_R7
SCALE: 1:1536
UNITS: in.[mm]
REV. BY: SKR

Preliminary Design

Figure 36. Bill of Materials, Test No. MWP-1

Item No.	QTY.	Description	Material Spec
c1	36	3"x1-3/4"x7 Gauge [76x44x4.6], 83" [2108] Long Bent Z-Section Post	Hot-Rolled ASTM A1011 HSLA Gr. 50
c2	108	12 Gauge Tabbed Bracket - Version 10	Hot-Rolled ASTM A1011 HSLA Grade 50
c3	108	5/16" [8] Dia. UNC, 1" [25] Long Hex Cap Screw and Nut	Bolt SAE J429 Gr. 5 or ASTM A449/Nut ASTM A563 DH
c4	36	Straight Rod - ϕ3/16" [5] Cable Clip	ASTM B16 Brass C36000 Half Hard (HO2), ROUND. TS >= 68.0 ksi, YS >= 52.0 ksi
d1	1	3/4" [19] Dia. High Strength Pre-Stretched Cable Guiderail	3x7 Cl A Galv.
d2	16	7/8" [22] Dia. Hex Nut	ASTM A563C
d3	28	Cable End Threaded Rod	ASTM A449
d4	24	Bennet Cable End Fitter	ASTM A47
d5	24	7/8" [22] Dia. Square Nut	SAE J429 Gr. 5
e1	8	Bennet Short Threaded Turnbuckle	Not Specified
e2	8	Threaded Loadcell Coupler	N/A
e3	4	50,000-lb [222.4-kN] Load Cell	N/A

Preliminary Design

MwRSF	Midwest 4-Cable Barrier System		SHEET: 24 of 24
			DATE: 07/28/2015
Midwest Roadside Safety Facility	Bill of Materials		DRAWN BY: JGP/ESG/SDB/JAH
	DWG. NAME. 4CMB-ZPost_R7	SCALE: 1:1536 UNITS: in.[mm]	REV. BY: SKR

Figure 37. Bill of Materials, Test No. MWP-1

Figure 38. Test Installation Photographs, Test No. MWP-1

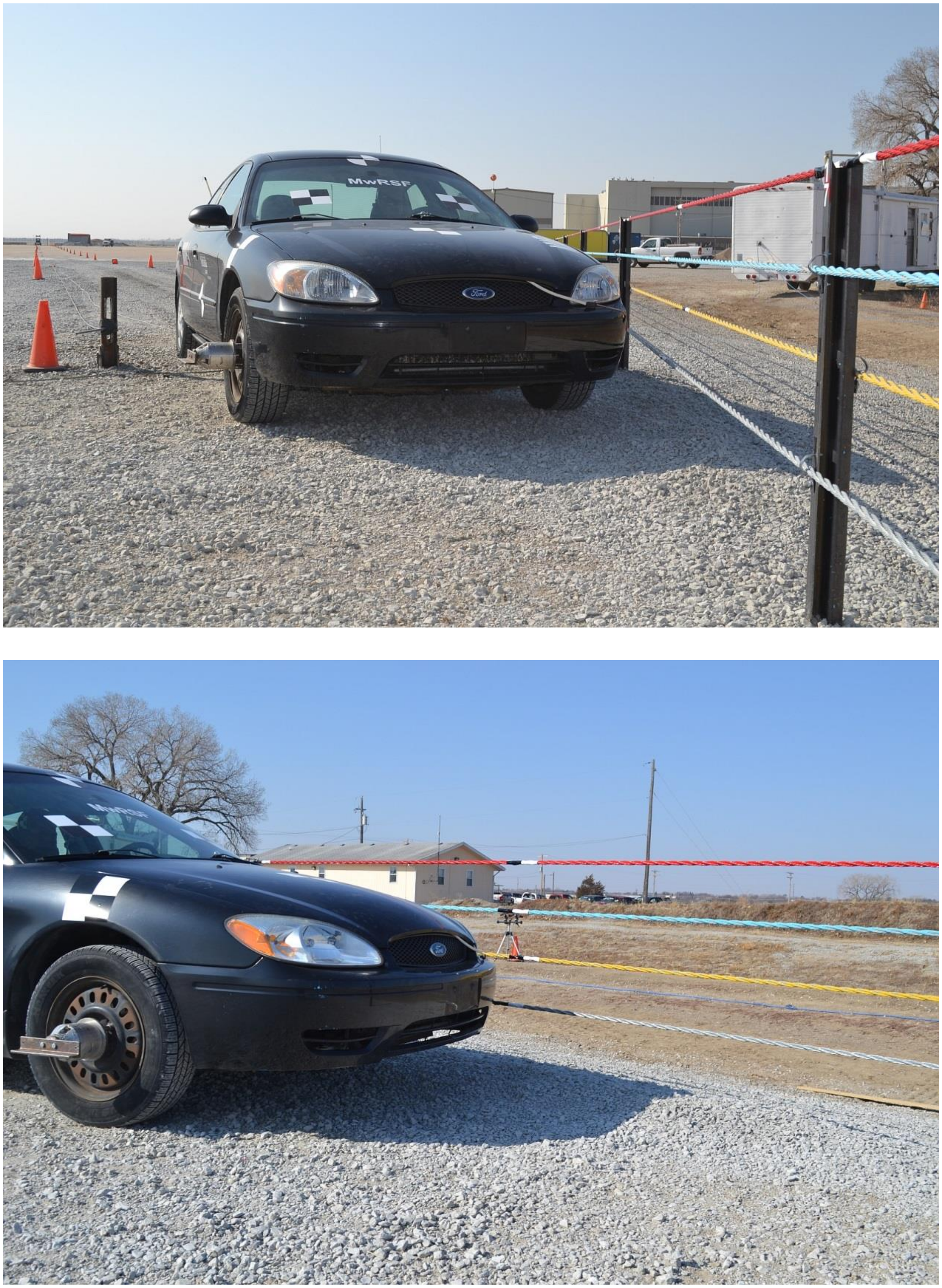


Figure 39. Cable Heights Relative to Test Vehicle, Test No. MWP-1

5 FULL-SCALE CRASH TEST NO. MWP-1

5.1 Static Soil Test

Before full-scale crash test no. MWP-1 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH. The static test results, as shown in Appendix C, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

5.2 Test No. MWP-1

The 3,298-lb (1,496-kg) passenger vehicle impacted the high-tension four-cable median barrier at a speed of 60.4 mph (97.2 km/h) and an angle of 27.9 degrees. A summary of the test results and sequential photographs are shown in Figure 40. Additional sequential photographs are shown in Figures 41 through 43.

5.3 Weather Conditions

Test no. MWP-1 was conducted on March 26, 2014 at approximately 1:45 p.m. The weather conditions, as per the National Oceanic and Atmospheric Administration (station 14939/LNK), were reported and are shown in Table 4.

Table 4. Weather Conditions, Test No. MWP-1

Temperature	63° F
Humidity	26 %
Wind Speed	33 mph
Wind Direction	18° from True North
Sky Conditions	Sunny
Visibility	9 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0 in.
Previous 7-Day Precipitation	0 in.

5.4 Test Description

Initial vehicle impact was to occur 8 ft (2.4 m) downstream from post no. 16, as shown in Figure 44, which was selected according to MASH. The actual point of impact was approximately 9 in. (229 mm) downstream from the target impact point. A sequential description of the impact events is contained in Table 5. The vehicle came to rest in line with the system 180 ft – 3 in. (54.9 m) downstream from the point of impact between post nos. 27 and 28. The vehicle trajectory and final position are shown in Figures 40 and 45.

Table 5. Sequential Description of Impact Events, Test No. MWP-1

TIME (sec)	EVENT
0.000	Vehicle front bumper contacted cable no. 1 between post no. 16 and 17.
0.002	The left side of the vehicle began to deform.
0.010	Vehicle left headlight contacted cable no. 2 between posts no. 16 and 17.
0.014	Vehicle left fender contacted cable no. 3.
0.022	Post no. 16 began to deflect downstream and post no. 17 began to deflect backward.
0.032	Post nos. 18 and 19 began to bend backward and the vehicle left fender contacted cable no. 2.
0.042	Post nos. 14 and 15 began to deflect backward.
0.060	Vehicle left-front tire overrode cable no. 1 and cable no. 3 slid up the left side of the hood.
0.062	Vehicle left A-pillar contacted cable no. 4.
0.066	Vehicle left A-pillar contacted cable no. 3 and began to deform.
0.072	The vehicle front bumper impacted post no. 17.
0.074	Cable no. 2 detached from post no. 17 and the vehicle hood began to deform.
0.080	Cable no. 4 detached from post no. 17.
0.094	Post nos. 16 through 20 were bending backward. The left side mirror disengaged as cable no. 4 slid up the A-pillar.
0.112	Cable no. 3 detached from post no. 16 and 18.
0.122	Vehicle left-front tire became airborne.
0.134	Vehicle left headlight began to detach.
0.144	Vehicle left door began to deform from contact with cable no. 2.
0.148	Vehicle left-rear tire overrode cable no. 1.
0.156	Cable no. 4 detached from post no. 18. Cable no. 4 slid over the A-pillar and on to the roof as the vehicle underrode it.

0.166	Cable no. 4 detached from post no. 16.
0.174	The vehicle began to roll toward the barrier (down into the ditch).
0.186	Cable no. 2 detached from post no. 18.
0.190	Vehicle right-front tire overrode cable no. 1. Cable no. 3 slid up the A-pillar to the roof as the vehicle underrode it.
0.192	Post no. 21 began to deflect backward and cable no. 2 detached from post nos. 15 and 19.
0.232	Cable no. 4 lost contact with the vehicle.
0.234	Vehicle right rear tire overrode cable no. 1.
0.240	Cable no. 2 detached from post no. 20.
0.254	Cable no. 2 detached from post no. 21.
0.272	Cable no. 3 lost contact with the vehicle.
0.282	Vehicle left-rear tire became airborne.
0.312	Vehicle right-rear tire became airborne as it entered the V-ditch.
0.452	Vehicle left-rear tire regained contact with the ground.
0.462	Vehicle left-front tire ruptured.
0.548	Vehicle was parallel to the system.
0.566	Vehicle began to yaw toward the barrier as the left headlight detached.
0.850	Vehicle reached its maximum lateral position 153 in. (3.9 m) behind post no. 20.
0.910	Vehicle began to yaw away from the barrier.
2.012	Vehicle contacted post no. 24 as the right-side of the vehicle returned to be in line with the system.
2.120	Vehicle right-front bumper contacted post no. 25 and it bent downstream.
2.188	Vehicle right fender contacted cable no. 3.
2.242	Vehicle right A-pillar contacted cable no. 4.
2.426	Vehicle front bumper contacted post no. 26.
2.432	Vehicle right-front tire ruptured.
2.878	Vehicle front bumper contacted post no. 27.
3.800	Vehicle came to rest in line with the system, 180 ft-3 in. (54.9 m) downstream of impact.

5.5 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 46 through 50. Barrier damage consisted of bent posts, disengaged cables, and deformed brackets. At its final resting position, the vehicle was still in contact with the cables. Cable no. 2 was on the left side and the remaining cables were on the right side.

Cable no. 4 disengaged from post nos. 16 through 19, as well as post nos. 24 through 28, due to fracture of the brass keeper rods. Cable no. 3 disengaged from post nos. 12 through 20 and 25 through 28, cable no. 2 disengaged from post nos. 17 through 28, and cable no. 1 disengaged from post nos. 17, and 23 through 28. All of the brackets releasing cable no. 2 fractured due to high lateral cable loads pulling away from the posts. All other brackets releasing cables nos. 1 and 3 opened up with the tabs rotating through the keyway to release the cables vertically. Separation of the cable splices was documented, but the displacements were small. The maximum displacement at a splice was ¼ in. (6 mm) at the splice of cable no. 2.

Post nos. 16 through 29 had varying degrees of plastic deformations in the form of bending and twisting. The posts typically twisted to face upstream, unless they were directly contacted by the vehicle. Post nos. 17 and 25 through 27 were bent nearly to the groundline from the vehicle running over them. All bent posts formed plastic hinges at or just below the groundline.

The maximum dynamic deflection of the system was 148 in. (3.8 m), and the working width of the system was 153 in. (3.9 m), as determined from high-speed video analysis. The upstream anchor was displaced ⅛ in. (3 mm) downstream. The downstream anchor did not show signs of displacement.

5.6 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 51 through 53. The maximum occupant compartment deformations are listed in Table 6 along with the deformation limits established in MASH for various areas of the occupant compartment. Note that none of the MASH-established deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

Table 6. Maximum Occupant Compartment Deformations by Location

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	¼ (6)	≤ 9 (229)
Floor Pan & Transmission Tunnel	0 (0)	≤ 12 (305)
Side Front Panel (in Front of A-Pillar)	¼ (6)	≤ 12 (305)
Side Door (Above Seat)	½ (13)	≤ 9 (229)
Side Door (Below Seat)	¼ (6)	≤ 12 (305)
Roof	2½ (64)	≤ 4 (102)

The majority of the vehicle damage was concentrated on the left-front corner and left side of the vehicle where the impact occurred. The front bumper was under the front of the car. The left-front fender disengaged from the front bumper. There was a 2½-in. (64-mm) gap at the left headlight on the fender. The left-front tire was torn and a 10½-in. (267-mm) tear was located on the left-front fender. There were scrapes and gouges along the left side of the vehicle. Gouges were present along the A-pillar, and there were multiple cracks along the left side of the windshield. The left-side mirror was disengaged. There was a 6- in. (152-mm) wide, 32-in. (813-mm) long tear in the left-front door, starting at the back of the left-front fender and continuing along the left side of the car. The roof was scraped from the cables and was indented 2½ in. (64 mm). There was a 12-in. (305-mm) long dent on the right-rear quarter panel. The right side of the vehicle was scraped, including the right-front rim. The right-front bumper was crushed around post no. 28. The right-front headlight was broken but still attached. The remaining window glass remained undamaged. Minor scrapes were found on the undercarriage along the engine and transmission oil pans, control arms, exhaust pipe, and driver's side floor pan. A 23-in. (584-mm) long and ¼-in. (6.4-mm) deep gouge was located on the fuel tank.

5.7 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 7. The SLICE 1 failed to record data due to a faulty trigger. Note that the OIVs and ORAs were within the suggested limits provided in MASH. The calculated THIV, PHD, and ASI values are also shown in Table 7. The results of the occupant risk analysis, as determined from the accelerometer data, are also summarized in Figure 40. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E.

Table 7. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MWP-1

Evaluation Criteria		**Transducer**		**MASH Limits**
		SLICE 1	**SLICE 2 (Primary)**	
OIV ft/s (m/s)	Longitudinal	NA	-8.50 (-2.59)	≤ 40 (12.2)
	Lateral	NA	9.42 (2.87)	≤40 (12.2)
ORA g's	Longitudinal	NA	-5.08	≤ 20.49
	Lateral	NA	5.37	≤ 20.49
MAX. ANGULAR DISPL. deg.	Roll	NA	-13.59	≤75
	Pitch	NA	-4.26	≤75
	Yaw	NA	32.12	not required
THIV ft/s (m/s)		NA	12.70 (3.87)	not required
PHD g's		NA	5.63	not required
ASI		NA	0.31	not required

5.8 Load Cells and String Potentiometers

The pertinent data from the load cells and string potentiometer was extracted from the bulk signal and analyzed using the transducers' calibration factors. The maximum displacement of the upstream anchor was recorded as 0.26 in. (7 mm), while a summary of the maximum cable loads can be found in Table 8. The recorded data and analyzed results are detailed in Appendix F. The exact moment of impact could not be determined from the transducer data, as impact may have occurred prior to a measurable signal increase in the data. Thus, the extracted data curves should not be taken as precise time after impact, but rather a general timeline between events within the data curve itself.

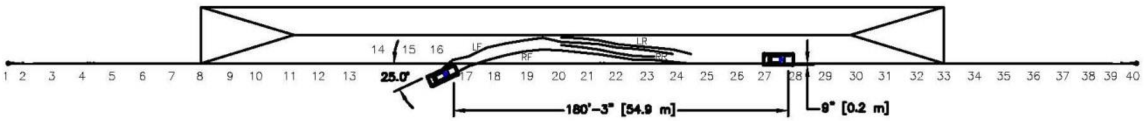
Table 8. Maximum Cable Loads, Test No. MWP-1

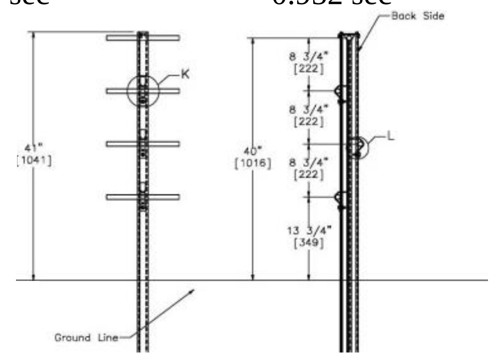
Cable Location	Sensor Location	Maximum Cable Load		Time
		kips	kN	(sec)
Combined Cable Load	Upstream of Impact	32.56	144.83	0.615
Cable No. 4	Upstream of Impact	5.47	24.33	0.111
Cable No. 3	Upstream of Impact	6.13	27.27	0.222
Cable No. 2	Upstream of Impact	21.15	94.08	0.673
Cable No. 1	Upstream of Impact	7.08	31.49	2.544

5.9 Discussion

The analysis of the test results for test no. MWP-1 showed that the high-tension four-cable median barrier adequately contained and redirected the 1500A vehicle, with controlled lateral displacements of the barrier. There were no detached elements or fragments which showed potential for penetrating the occupant compartment or which presented undue hazard to other traffic. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate or ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix E, were deemed acceptable, because they did not adversely influence occupant risk safety criteria or cause rollover. After impact, the vehicle was captured and retained within the system, so there was no exit information. Therefore, test no. MWP-1 conducted on the four-cable median barrier was determined to be acceptable according to the MASH safety performance criteria for test designation no. 3-17.

0.000 sec 0.096 sec 0.254 sec 0.566 sec 0.952 sec





- Test Agency .... MwRSF
- Test Number MWP-1
- Date 3/26/2014
- MASH Test Designation 3-17
- Test Article .... Four-Cable Median Barrier
- Total Length .... 608 ft (185.3 m)
- Key Component .... Bolted Tab Bracket v_10
- Key Component – Cable
  - Size .... 3x7, ¾-in. (19-mm) diameter
  - Cable Heights .... 13¾, 22½, 31¼, 40 in. (349, 572, 794, 1,016 mm)
- Key Component – MWP
  - Dimensions .... 3 x 1¾ x 83 in. (76 x 44 x 2,108 mm)
  - Spacing .... 16 ft (4.9 m)
- Soil Type .... Compacted, coarse, crushed limestone
- Vehicle Make /Model .... 2006 Ford Taurus
  - Curb .... 3,205 lb (1,454 kg)
  - Test Inertial .... 3,298 lb (1,496 kg)
  - Gross Static .... 3,462 lb (1,570 kg)
- Impact Conditions
  - Speed .... 60.4 mph (97.2 km/h)
  - Angle .... 27.9 deg
  - Impact Location .... 8 ft 9 in. (2.7 m) downstream of post no. 16
- Impact Severity (IS) .... 86.2 kip-ft (116.9 kJ) > 75.7 kip-ft (102.6 kJ)
- Exit Conditions
  - Speed .... NA
  - Angle .... NA
- Exit Box Criterion .... NA (Did not exit system)
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 180 ft 3 in. (54.9 m)
- Vehicle Damage .... Moderate
  - VDS [14] 11-LFQ-5
  - CDC [15] 11-LYAK-8
  - Maximum Interior Deformation .... ½ in. (13 mm)
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set .... NA
  - Dynamic .... 148 in. (3.8 m)
  - Working Width .... 153 in. (3.9 m)
- Transducer Data

Evaluation Criteria		Transducer: SLICE 1	Transducer: SLICE 2 (Primary)	MASH Limit
OIV ft/s (m/s)	Longitudinal	NA	-8.50 (-2.59)	≤ 40 (12.2)
	Lateral	NA	9.42 (2.87)	≤ 40 (12.2)
ORA g's	Longitudinal	NA	-5.08	≤ 20.49
	Lateral	NA	5.37	≤ 20.49
MAX ANGULAR DISP. deg.	Roll	NA	-13.59	≤75
	Pitch	NA	-4.26	≤75
	Yaw	NA	32.12	not required
THIV – ft/s (m/s)		NA	12.70 (3.87)	not required
PHD – g's		NA	5.63	not required
ASI		NA	0.31	not required

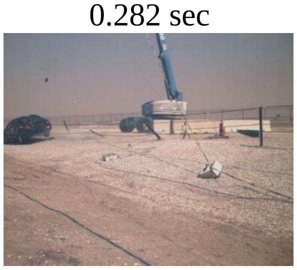
Figure 40. Summary of Test Results and Sequential Photographs, Test No. MWP-1


0.000 sec


0.060 sec


0.166 sec


0.282 sec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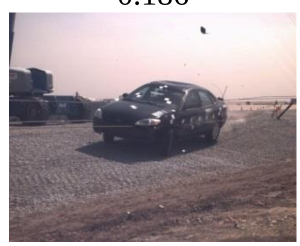
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Figure 41. Additional Sequential Photographs, Test No. MWP-1

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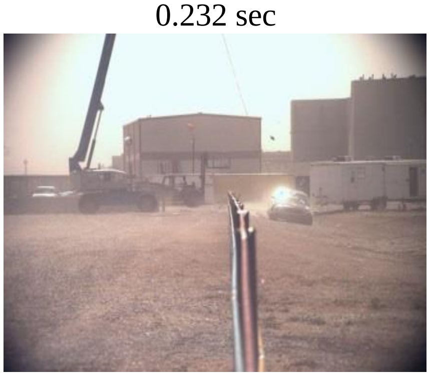

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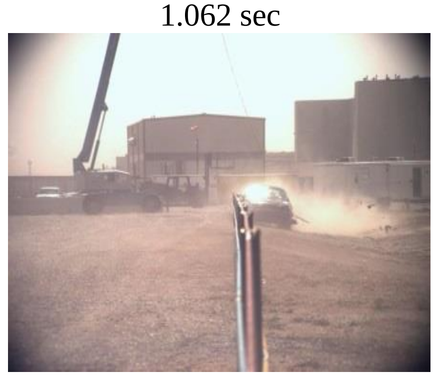

2.026 sec

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Figure 42. Additional Sequential Photographs, Test No. MWP-1


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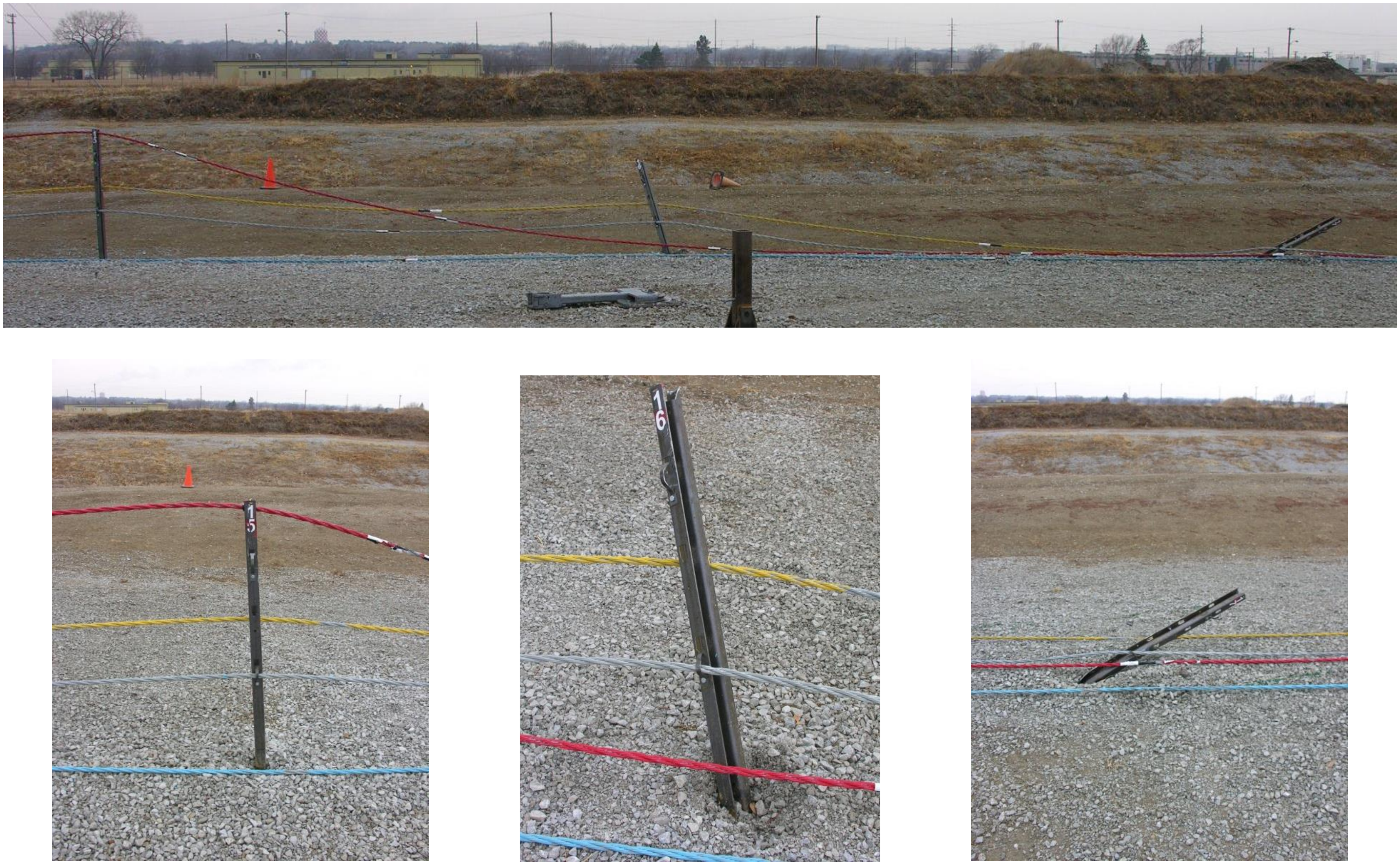
0.784 sec


2.012 sec

Figure 43. Additional Sequential Photographs, Test No. MWP-1

Figure 44. Impact Location, Test No. MWP-1

Figure 45. Vehicle Final Position and Trajectory Marks, Test No. MWP-1



Post No. 15 Post No. 16 Post No. 17

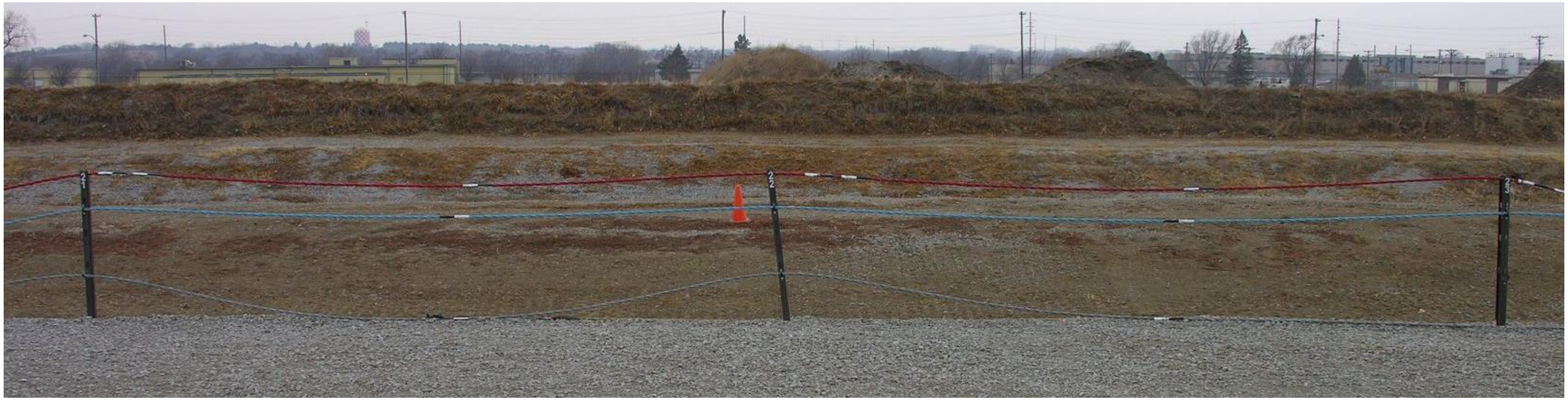
Figure 46. System Damage, Post Nos. 15 through 17, Test No. MWP-1

Post No. 18

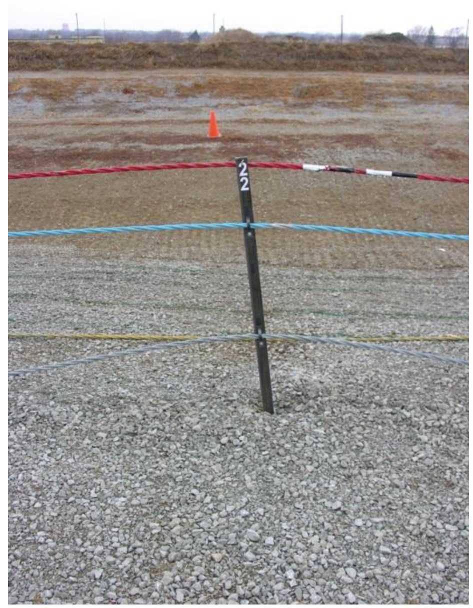
Post No. 19

Post No. 20

Figure 47. System Damage, Post Nos. 18 through 20, Test No. MWP-1



Post No. 21



Post No. 22

Post No. 23

Figure 48. System Damage, Post Nos. 21 through 23, Test No. MWP-1

Post No. 24

Post No. 25

Post No. 26

Figure 49. System Damage, Post Nos. 24 through 26, Test No. MWP-1

Post No. 27

Post No. 28

Post No. 29

Figure 50. System Damage, Post Nos. 27 through 29, Test No. MWP-1

Figure 51. Vehicle Damage, Test No. MWP-1

Figure 52. Vehicle Damage, Left Side and Roof, Test No. MWP-1

Figure 53. Vehicle Damage, Undercarriage, Test No. MWP-1

6 DESIGN DETAILS TEST NO. MWP-2

The four-cable barrier test installation for test no. MWP-2 was nearly identical to that of test no. MWP-1, but the installation was on level terrain in accordance with MASH test designation no. 3-11, as shown in Figure 54. Additionally, the system was mirrored so that cable no. 2 was on the impact side of the barrier, and cable nos. 1 and 3 were on the non-impact side. The spacing between post nos. 35 and 36 was reduced to 12 ft (3.7 m) in order to fit the entire system within the bounds of the test site. Thus, the total system length for test no. MWP-2 was 604 ft (184 m). The reduced post spacing was selected at post nos. 35 and 36 to be outside of the vehicle contact region and away from the system anchorage. Photographs of the test installation are shown in Figure 55. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

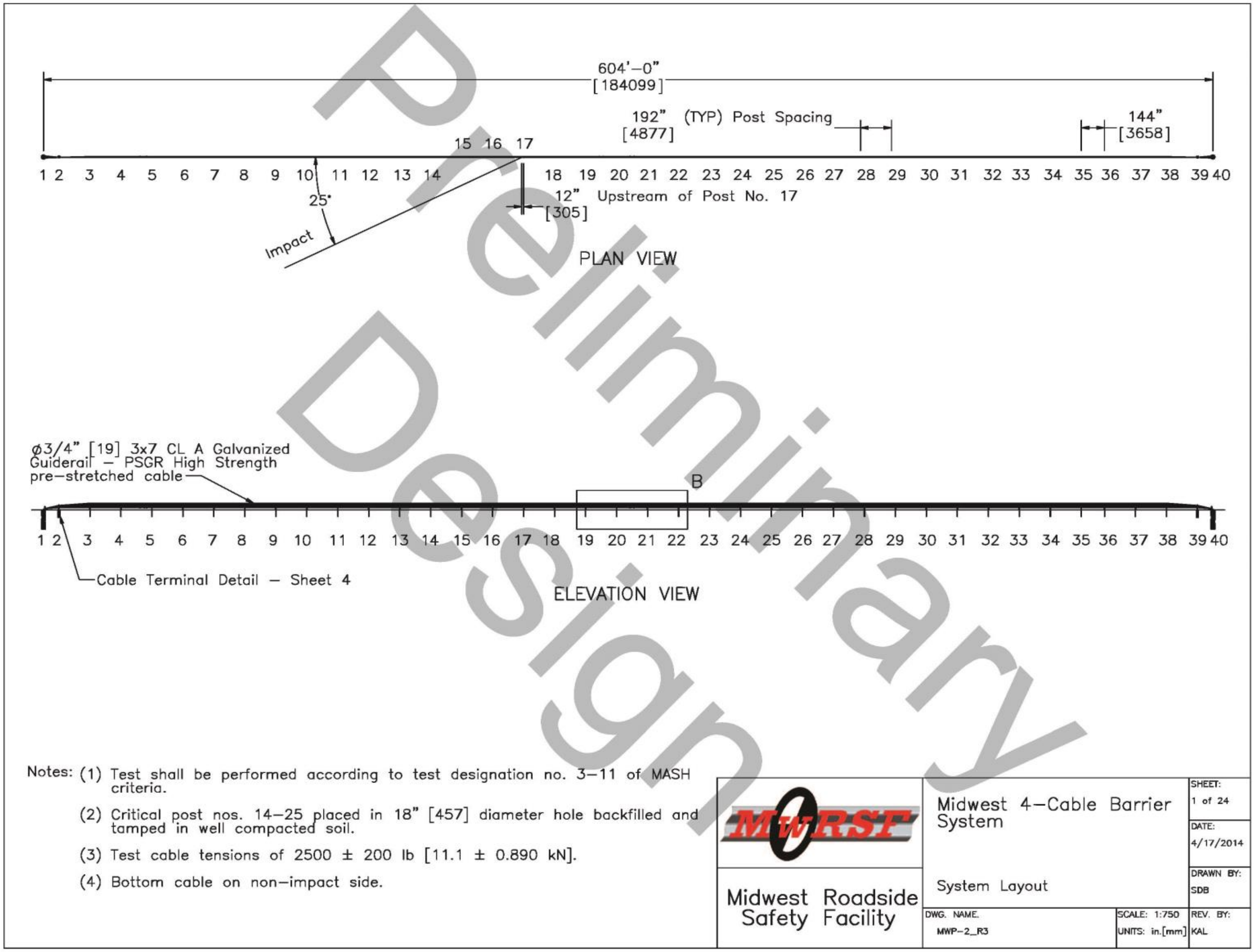


Figure 54. Test Installation Layout, Test No. MWP-2

Figure 55. Installation Photographs, Test No. MWP-2

7 FULL-SCALE CRASH TEST NO. MWP-2

7.1 Static Soil Test

Before full-scale crash test no. MWP-2 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH. The static test results, as shown in Appendix C, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

7.2 Test No. MWP-2

The 5,023-lb (2,278-kg) pickup truck impacted the high-tension four-cable median barrier at a speed of 62.1 mph (100.0 km/h) and an angle of 26.8 degrees. A summary of the test results and sequential photographs are shown in Figure 56. Additional sequential photographs are shown in Figures 57 through 59. Documentary photographs of the crash test are shown in Figures 60 and 61.

7.3 Weather Conditions

Test no. MWP-2 was conducted on April 18, 2014 at approximately 2:30 p.m. The weather conditions, as per the National Oceanic and Atmospheric Administration (station 14939/LNK), were reported and are shown in Table 9.

Table 9. Weather Conditions, Test No. MWP-2

Temperature	72° F
Humidity	30 %
Wind Speed	24 mph
Wind Direction	160° from True North
Sky Conditions	Sunny
Visibility	8 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0 in.
Previous 7-Day Precipitation	1.14 in.

7.4 Test Description

Initial vehicle impact was to occur 12 in. (305 mm) upstream from post no. 17, as shown in Figure 62, which was selected according to MASH. The actual point of impact was approximately 11 in. (279 mm) upstream from post no. 17. A sequential description of the impact events is contained in Table 10. The vehicle came to rest 187 ft – 1 in. (57.0 m) downstream from the point of impact and 4 ft – 1 in. (1.2 m) laterally behind the barrier's initial position after successfully being captured by the barrier system. The vehicle trajectory and final position are shown in Figures 56 and 63.

Table 10. Sequential Description of Impact Events, Test No. MWP-2

Time (sec)	Event Description
0.000	Vehicle left-front bumper contacted cable no. 2 near post no. 17 and the post started to deflect downstream and backwards.
0.008	Vehicle left headlight contacted post no. 17 and began to crack.
0.016	Vehicle left fender contacted cable nos. 3 and 4 and began to deform. The left-front tire contacted post no. 17 causing the tire to rupture.
0.026	Cable no. 4 detached from post no. 17 and the left headlight shattered.
0.032	Vehicle left-front tire lost contact with the ground as it overrode post no. 17.
0.034	Cable no. 2 detached from post no. 17.
0.046	The left-front tire overrode cable no. 1.
0.060	The left-front tire contacted cable no. 3.
0.090	Cable no. 2 detached from post no. 18.
0.096	Vehicle left-front tire overrode cable no. 3.
0.098	Cable no. 2 detached from post no. 16 and cable no. 4 detached from post no. 18.
0.122	Vehicle left-front tire regained contact with the ground
0.138	Cable no. 2 detached from post no. 19.
0.142	Vehicle right-front tire overrode cable no. 1.
0.144	Cable no. 4 detached from post no. 19.
0.150	Vehicle began to roll toward the barrier and yaw away from the barrier.
0.162	The vehicle right-front bumper began to deform as it contacted post no. 18 causing post no. 18 to bend downstream.
0.172	Vehicle right-front tire contacted and overrode post no. 18.
0.186	Cable no. 4 detached from post no. 16.
0.196	Cable no. 2 detached from post no. 20.

0.222	Cable no. 4 detached from post nos. 20 and 21. Cable no. 2 detached from post no. 21.
0.228	Cable no. 4 detached from post no. 15.
0.252	Cable no. 2 detached from post no. 22.
0.268	Vehicle began to pitch downward as the right-front tire overrode cable no. 3.
0.318	Cable no. 4 detached from post no. 22.
0.332	Cable no. 4 detached from post no. 14.
0.344	Cable no. 4 detached from post no. 23.
0.370	Cable no. 4 detached from post no. 24.
0.402	Cable no. 4 detached from post no. 25.
0.424	Cable no. 4 detached from post no. 26.
0.468	Cable no. 4 detached from post no. 27 and the left-rear bumper contacted cable no. 4.
0.506	Cable no. 4 detached from post no. 28 and cable no. 2 detached from post no. 29.
0.518	Vehicle was parallel to the system.
0.550	Cable no. 4 detached from post no. 13 and cable no. 2 detached from post no. 31.
0.572	Cable no. 2 detached from post no. 32.
0.592	Cable no. 2 detached from post no. 33 and left-rear tire ruptured.
0.610	Cable no. 2 detached from post no. 34 and cable no. 4 detached from post no. 29.
0.632	Vehicle left fender contacted cable no. 4 splice. Cable no. 2 detached from post no. 35.
0.648	The vehicle left front door began to deform as cable no. 4 contacted it. Vehicle reached its maximum lateral position of 221 in. behind post no 21.
0.670	Vehicle left A-pillar began to deform and left front door began to separate.
0.698	Cable nos. 2 and 4 detached from post no. 12. Cable no. 4 detached from post no. 11.
0.740	Cable no. 4 detached from post no. 10. Vehicle began to yaw back toward barrier.
0.774	Cable no. 4 detached from post no. 9.
0.852	Vehicle left front bumper contacted cable no. 2 splice. Vehicle was again parallel to system.
0.916	Cable no. 4 detached from post no. 30.
0.966	Cable no. 4 detached from post no. 31.
1.030	Cable no. 4 detached from post no. 32.
1.204	Cable no. 4 detached from post no. 33.
1.238	Cable no. 4 detached from post no. 34.
4.600	Vehicle came to rest 187 ft – 1 in. (57.0 m) downstream of impact while still in contact with the barrier.

7.5 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 63 through 66. Barrier damage consisted of bent posts, disengaged cables, deformed cable brackets, and movement of cable end anchor foundations. At the vehicle's final resting place it was still in contact with the system, with cable nos. 2 and 4 resting on the impact side of the vehicle, while cable nos. 1 and 3 were overridden and were on the non-impact side of the vehicle.

Post nos. 8 through 34 had varying degrees of bending and twisting. The posts typically bent backward and toward the initial impact location, except for post nos. 17 and 18, which were directly impacted and run over, causing bending downstream and backward. Furthermore, post nos. 27 through 32 tore in the post flange around the bottom keyway on the impact side of the post, as seen in Figures 66 and 67. The posts typically fractured on the impact side between the keyway and free edge while buckling occurred on the back side of these posts.

Cable no. 2 released from the retaining brackets by exiting vertically and pulling the tabs out through the keyhole in post nos. 9 through 36. Similarly, cable no. 4 released from post nos. 9 through 34 by fracturing the brass retaining rod. The brass rods on post nos. 8 and 35 were bent but still attached. Cable nos. 1 and 3 typically deformed their respective brackets on post nos. 11 through 33, but these cables remained attached to the posts. Cable no. 3 only released from post nos. 18 and 19.

Both cable end anchor foundations were displaced in the soil. The upstream cable end anchor foundation displaced 1.55 in. (39 mm) as measured by the string potentiometer, while post-test examinations determined that the downstream cable end anchor foundation left a ½-in. (13-mm) soil gap on the downstream side. Post no. 2, the cable support post on the upstream end, was also slightly bent downstream from the tensile loading within the cables. The brass keeper rod on the downstream end cable anchor was bent. The maximum cable splice pullout of $^5/_8$ in. (16 mm) was observed on cable no. 4 at the load cell splice located between post nos. 4 and 5. The maximum dynamic deflection of the system was 219 in. (5,563 mm), and the working width of the system was 221 in. (5,613 mm), as determined from high-speed video analysis.

7.6 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figure 68. The maximum occupant compartment deformations are listed in Table 11 along with the deformation limits established in MASH for various areas of the occupant compartment. Note that none of the MASH-established deformation limits were violated. Complete occupant compartment and vehicle deformations are provided in Appendix D.

Table 11. Maximum Occupant Compartment Deformations by Location

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	$^3/_8$ (10)	≤ 9 (229)
Floor Pan & Transmission Tunnel	½ (13)	≤ 12 (305)
Side Front Panel (in Front of A-Pillar)	¼ (6)	≤ 12 (305)
Side Door (Above Seat)	¼ (6)	≤ 9 (229)
Side Door (Below Seat)	¾ (19)	≤ 12 (305)

The majority of the vehicle damage was concentrated on the left-front corner and left side of the vehicle where the impact occurred. The front bumper was kinked as the left side of the bumper was pushed inward. Similarly, the front of the left front fender was pushed/crushed inward. Scratches from the cable were found on the top-left of the front bumper. Scratches and gouges from the cables were found on the left side of the grille, and the grille was cracked horizontally above the center mark. The left headlight was shattered and only remained attached to the vehicle by the electrical cables. The left front quarter panel showed gouges from cable nos. 2 and 4. Two gouges from cable no. 4 were found at the mounting location of the left headlight. These gouges continued to the rear of the vehicle. Tearing and gouging occurred on the driver's side door from the two capture cables and their associated splice hardware. A 9-in. x 19-in.

(229x483-mm) dent was found in the driver's door. Tearing also occurred approximately a quarter of the way from the bottom of the door panel leaving a 21-in. x 5-in. (533x127-mm) section of torn and gouged sheet metal. The damage to the door caused the top of the driver's side door to bow outward, leaving a small gap between the body and the door frame. The left-front tire was deflated and gouged. Striation marks on the left-rear tire wall were visible, and the outer edge of the wheel rim was gouged along the entire circumference. A dent on the rear of the rear left quarter panel was also evident above the cable marks. A 2-in. (51-mm) dent was left in the left corner of the rear bumper.

Slight damage was found on the right side of the vehicle including a 7-in. (178-mm) dent located 20 in. (508 mm) right of center on the lower font bumper. Also, a 3-in. (76-mm) long cable mark was left on the right rear quarter panel in front of the rear wheel arch. A section of the lower rear portion of the right rear quarter panel was bent inward and upward underneath the rear quarter panel. Cable marks were also found on the outside of the right rear tire. Two small dents were found on the right half of the rear bumper.

7.7 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 12. Note that the OIVs and ORAs were within the suggested limits provided in MASH. The calculated THIV, PHD, and ASI values are also shown in Table 12. The results of the occupant risk analysis, as determined from the accelerometer data, are also summarized in Figure 56. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix G.

Table 12. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MWP-2

Evaluation Criteria		Transducer SLICE 1	Transducer SLICE 2 (Primary)	MASH Limits
OIV ft/s (m/s)	Longitudinal	-9.39 (-3.48)	-9.45 (-3.48)	≤ 40 (12.2)
	Lateral	8.66 (2.64)	9.18 (2.80)	≤40 (12.2)
ORA g's	Longitudinal	10.00	9.82	≤ 20.49
	Lateral	4.19	3.74	≤ 20.49
MAX. ANGULAR DISPL. deg.	Roll	-9.58	-8.27	≤75
	Pitch	-3.72	-3.63	≤75
	Yaw	27.98	27.28	not required
THIV ft/s (m/s)		12.70 (3.87)	12.93 (3.94)	not required
PHD g's		10.13	9.87	not required
ASI		0.29	0.27	not required

7.8 Load Cells and String Potentiometers

The pertinent data from the load cells and string potentiometer was extracted from the bulk signal and analyzed using each transducers' calibration factor. The maximum displacement of the upstream cable end anchor foundation was recorded as 1.55 in. (39 mm). A summary of the maximum cable loads can be found in Table 13. The recorded transducer data and analyzed results are detailed in Appendix H. The exact moment of impact could not be determined from the transducer data, as impact may have occurred prior to a measurable signal increase in the data. Thus, the extracted data curves should not be taken as precise time after impact, but rather a general timeline between events within the data curve itself.

Table 13. Maximum Cable Loads

Cable Location	Sensor Location	Maximum Cable Load		Time (sec)
		kips	kN	
Combined Cable Load	Upstream of Impact	39.25	174.60	0.471
Cable No. 4	Upstream of Impact	16.27	72.39	0.690
Cable No. 3	Upstream of Impact	8.71	38.77	0.262
Cable No. 2	Upstream of Impact	19.90	88.52	0.458
Cable No. 1	Upstream of Impact	5.80	25.81	0.187

7.9 Discussion

The analysis of the test results for test no. MWP-2 showed that the four-cable high-tension median barrier system adequately contained and redirected the 2270P vehicle, with controlled lateral displacements of the barrier. There were no detached elements or fragments which showed potential for penetrating the occupant compartment or which presented undue hazard to other traffic. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate or ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix G, were deemed acceptable, because they did not adversely influence occupant risk safety criteria or cause rollover. After impact, the vehicle trajectory was limited by the barrier system and was brought to rest 187 ft – 1 in. (57.0 m) downstream from the point of impact. Therefore, test no. MWP-2 conducted on the four-cable high-tension median barrier system was determined to be acceptable according to the MASH safety performance criteria for test designation no. 3-11.

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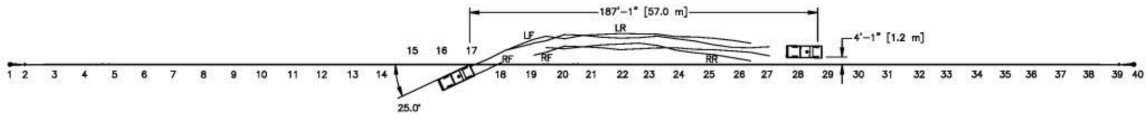

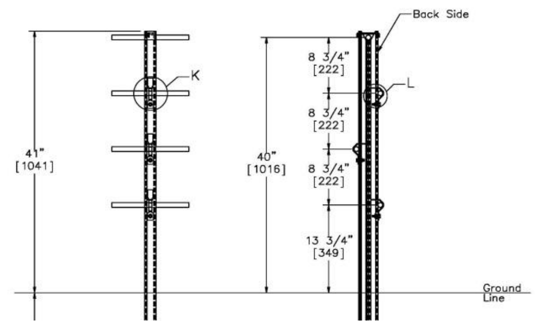

- Test Agency .... MwRSF
- Test Number........ MWP-2
- Date 4/18/2014
- MASH Test Designation 3-11
- Test Article........ Four-Cable Median Barrier
- Total Length .... 604 ft (184.1 m)
- Key Component – Bolted Tab Bracket v_10
- Key Component – Cable
  - Size .... 3x7, ¾-in. (19-mm) diameter
  - Cable Heights .... 13¾, 22½, 31¼, 40 in. (349, 572, 794, 1,016 mm)
- Key Component - MWP
  - Dimensions........ 3 x 1¾ x 83 in. (76 x 44 x 2,108 mm)
  - Spacing .... 16 ft (4.9 m)
- Soil Type .... Compacted, coarse, crushed limestone
- Vehicle Make /Model........ 2008 Dodge Ram
  - Curb........ 5,058 lb (2,294 kg)
  - Test Inertial........ 5,023 lb (2,278 kg)
  - Gross Static........ 5,189 lb (2,354 kg)
- Impact Conditions
  - Speed .... 62.1 mph (100.0 km/h)
  - Angle .... 26.8 deg
  - Impact Location........ 12 in. (305 mm) upstream of post no. 17
- Impact Severity (IS) .... 129.9 kip-ft (176.1 kJ) > 106 kip-ft (144 kJ) limit from MASH
- Exit Conditions
  - Speed .... NA
  - Angle .... NA
- Exit Box Criteria .... NA (Did not exit the system)
- Vehicle Stability........ Satisfactory
- Vehicle Stopping Distance .... 187 ft – 1 in.
- Vehicle Damage........ Moderate
  - VDS [14] 11-LFQ-3
  - CDC [15] 11-LFEN-5
  - Maximum Interior Deformation .... ¾ in. (19 mm)
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set .... NA
  - Dynamic........ 219 in. (5,563 mm)
  - Working Width........ 221 in. (5,613 mm)
- Transducer Data

Evaluation Criteria		Transducer		MASH Limit
		SLICE 1	SLICE 2 (Primary)	
OIV ft/s (m/s)	Longitudinal	-9.39 (-3.48)	-9.45 (-3.48)	≤ 40 (12.2)
	Lateral	8.66 (2.64)	9.18 (2.80)	≤ 40 (12.2)
ORA g's	Longitudinal	10.00	9.82	≤ 20.49
	Lateral	4.19	3.74	≤ 20.49
MAX ANGULAR DISP. deg.	Roll	-9.58	-8.27	≤75
	Pitch	-3.72	-3.63	≤75
	Yaw	27.98	27.28	not required
THIV – ft/s (m/s)		12.70 (3.87)	12.93 (3.94)	not required
PHD – g's		10.13	9.87	not required
ASI		0.29	0.27	not required

Figure 56. Summary of Test Results and Sequential Photographs, Test No. MWP-2


0.000 sec


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0.198 sec


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0.888 sec


1.298 sec


0.000 sec


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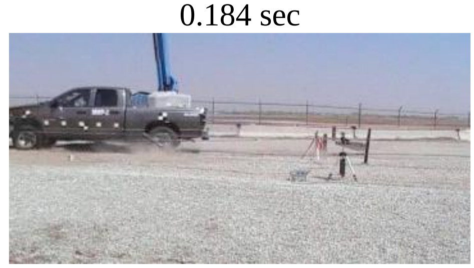
0.122 sec


0.184 sec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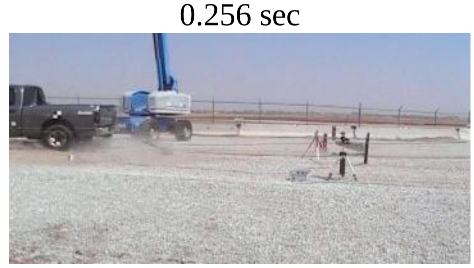
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Figure 57. Additional Sequential Photographs, Test No. MWP-2

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Figure 58. Additional Sequential Photographs, Test No. MWP-2

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0.068 sec

0.170 sec

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0.550 sec

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Figure 59. Additional Sequential Photographs, Test No. MWP-2

Figure 60. Documentary Photographs, Test No. MWP-2

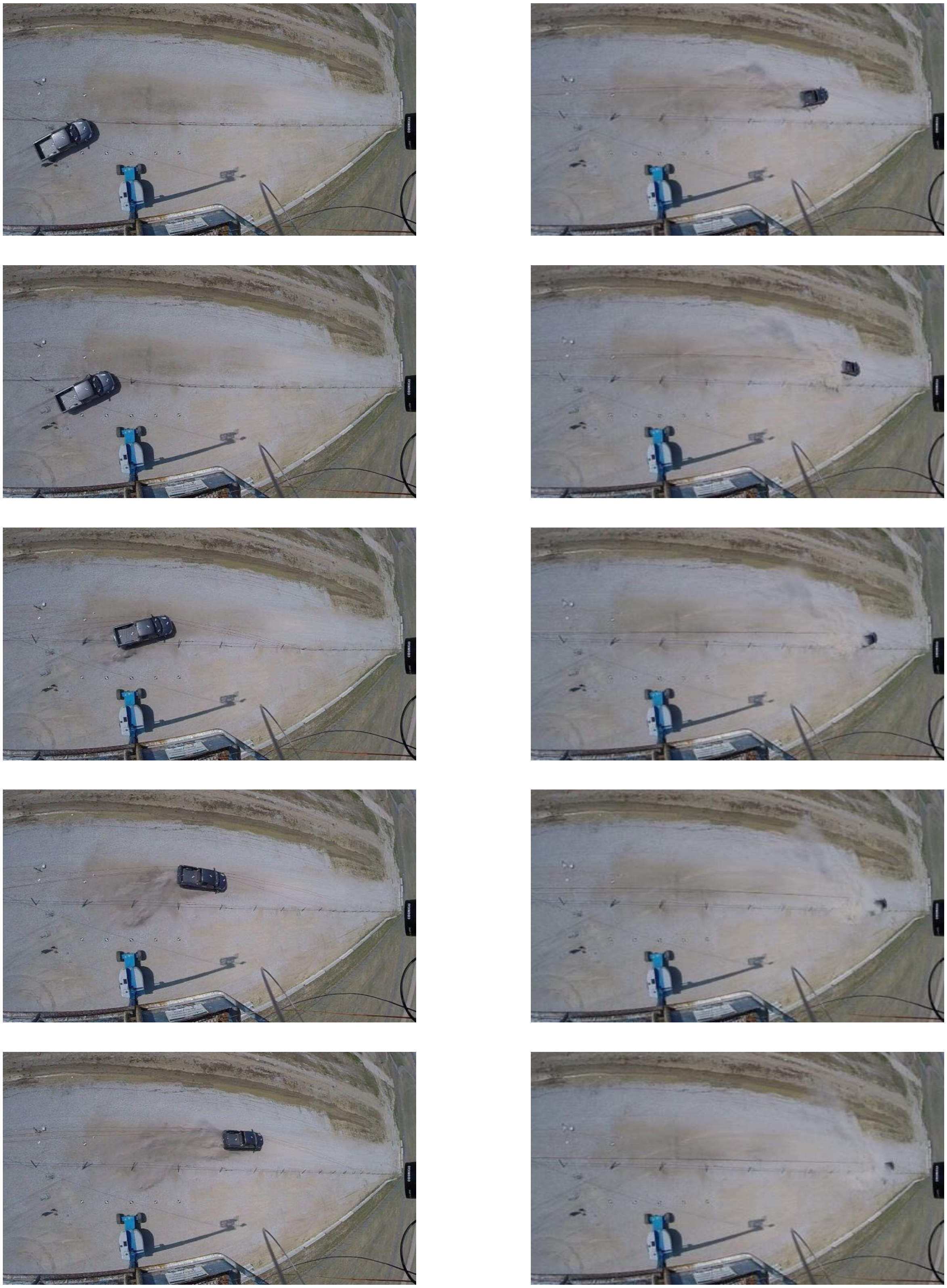
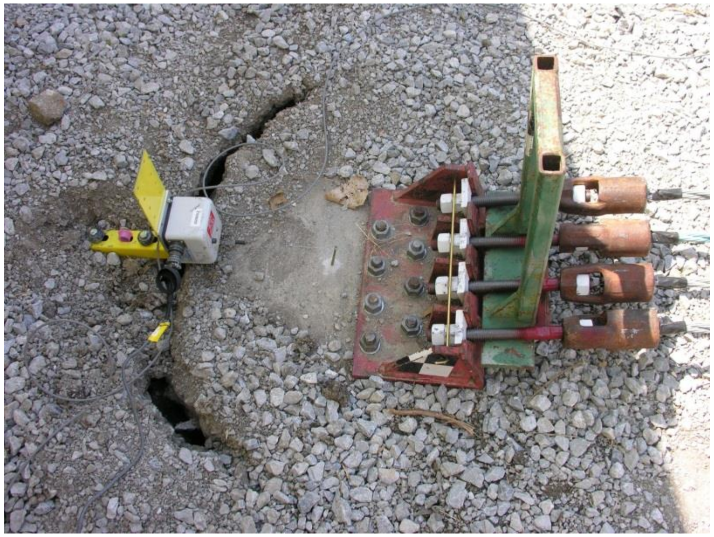


Figure 61. Documentary Photographs, Test No. MWP-2

Figure 62. Impact Location, Test No. MWP-2

Figure 63. Vehicle Trajectory and Final Position, Test No. MWP-2

Figure 64. Damage to System, Test No. MWP-2

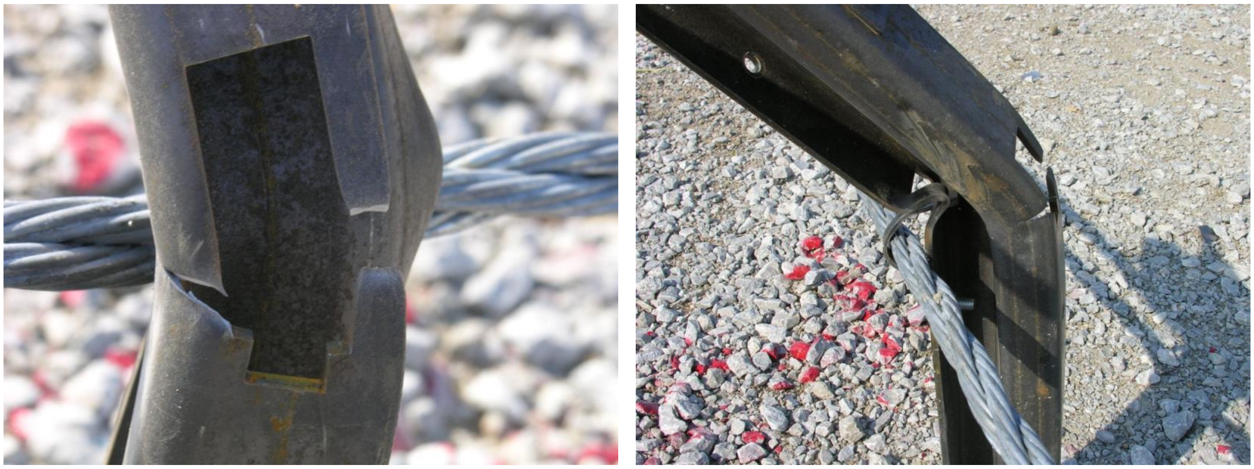


Upstream Anchor

Downstream Anchor

Post No. 2

Figure 65. Damage to Anchorages, Test No. MWP-2

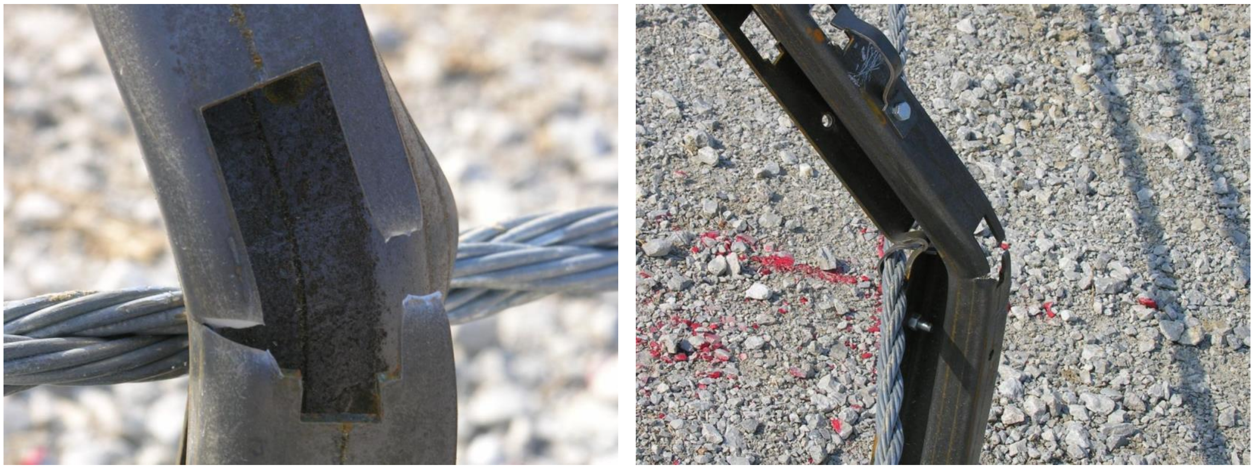


Post No. 27

Post No. 28

Post No. 29

Figure 66. Damage to Lower Keyhole, Post Nos. 27 through 29, Test No. MWP-2



Post No. 30

Post No. 31

Post No. 32

Figure 67. Damage to Lower Keyhole, Post Nos. 30 through 32, Test No. MWP-2

Figure 68. Vehicle Damage, Test No. MWP-2

8 DESIGN DETAILS TEST NO. MWP-3

The four-cable barrier test installation for test no. MWP-3 was similar to that of test nos. MWP-1 and MWP-2, but it utilized a refined design that varied from the previous tests in a number of key aspects. First, the installation utilized a half-post spacing of 8 ft (2.4 m). Similar to test no. MWP-2, the system remained oriented with cable no. 2 on the impact side of the barrier and cable nos. 1 and 3 on the non-impact side. Second, the spacing between post nos. 68 and 69 was 12 ft (3.7 m) in order to utilize the same anchors from MWP-2. Thus, the total system length for test no. MWP-3 remained 604 ft (184 m). The enlarged post spacing was selected to be outside of the vehicle contact region and away from the system anchorage.

Modifications were made to the system posts in order to prevent the MWPs from bending and tearing at the keyways for cable no. 1 as seen in test no. MWP-2. The keyways were adjusted so that each post contained only four keyways as opposed to the six seen in the previous tests. Three keyways were placed on one side of each post at the same heights used previously. However, the opposite side had only one keyway, located at the middle cable position. This modification eliminated the symmetry of the posts, but still allowed for median and roadside versions of the system (all cables on front) with a single post. The sizes of the keyways were also modified. The height of the upper portion of each keyway was reduced by ¼ in. (6 mm) to increase the buckling strength of the steel strip located between the keyway and the free edge of the post. This change was intended to increase bending strength in the post and prevent plastic hinges from forming around the first cable keyway. Based on analysis of previous bogie testing results, this reduced keyway height was determined to not affect the bracket exiting the keyway. Finally, the tops of the posts were extended ¼ in. (6 mm) to prevent damage to the brass rod installation slot in the post flange when driving the posts into the ground. During installation of the posts for test no. MWP-2 some of the slots closed slightly from the repeated impacts of the driver, and the brass rods were difficult to install. The added material above the slots should strengthen the post and prevent the slot from deforming. However, the bottom of the V-notch holding the top-cable was also deepened ¼ in. (6 mm) with the extension. This adjustment produced slightly steeper slopes for the V-notch. The complete drawing set can be found in Figures 69 through 92. Photographs of the test installation are shown in Figure 93. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

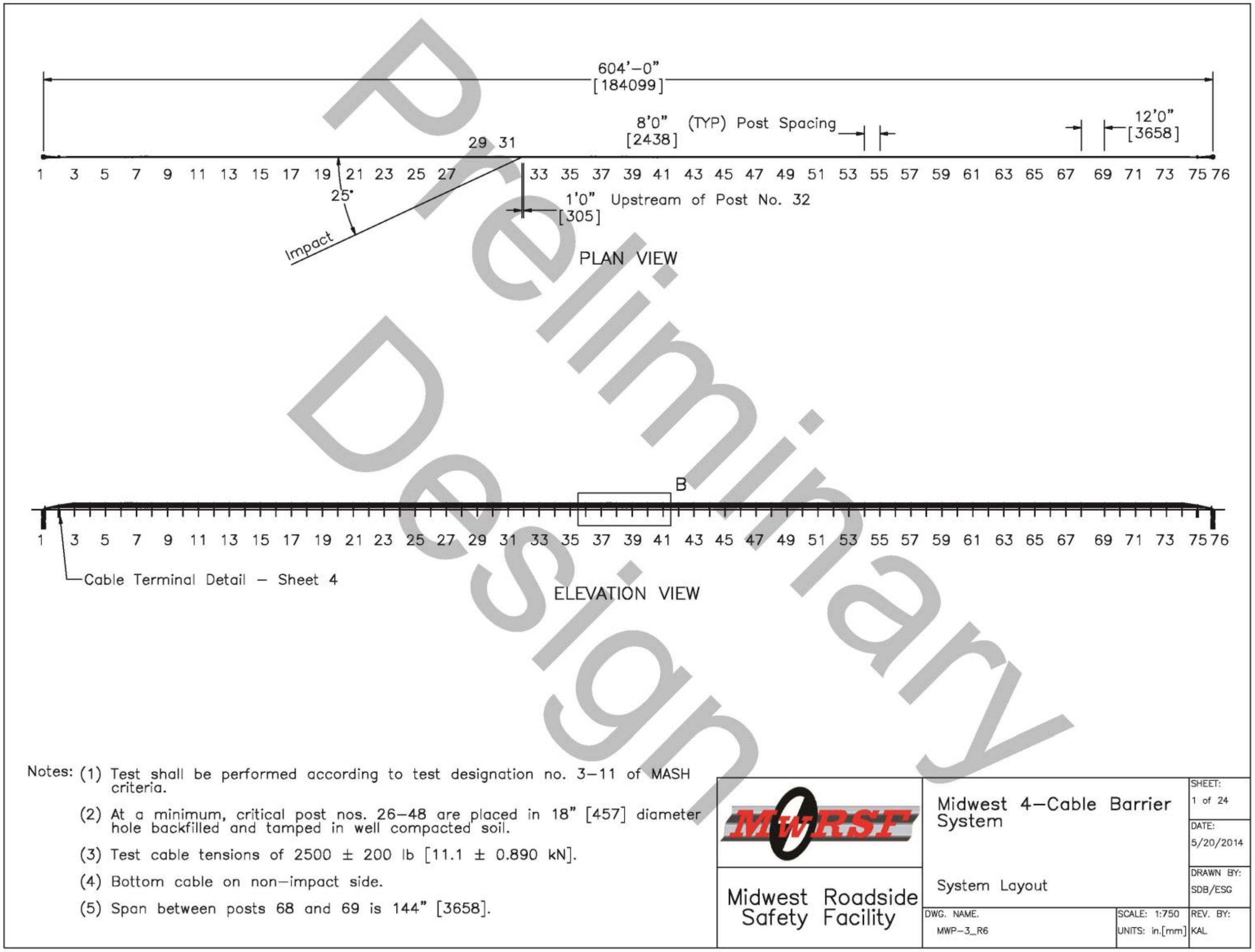


Figure 69. Test Installation Layout, Test No. MWP-3

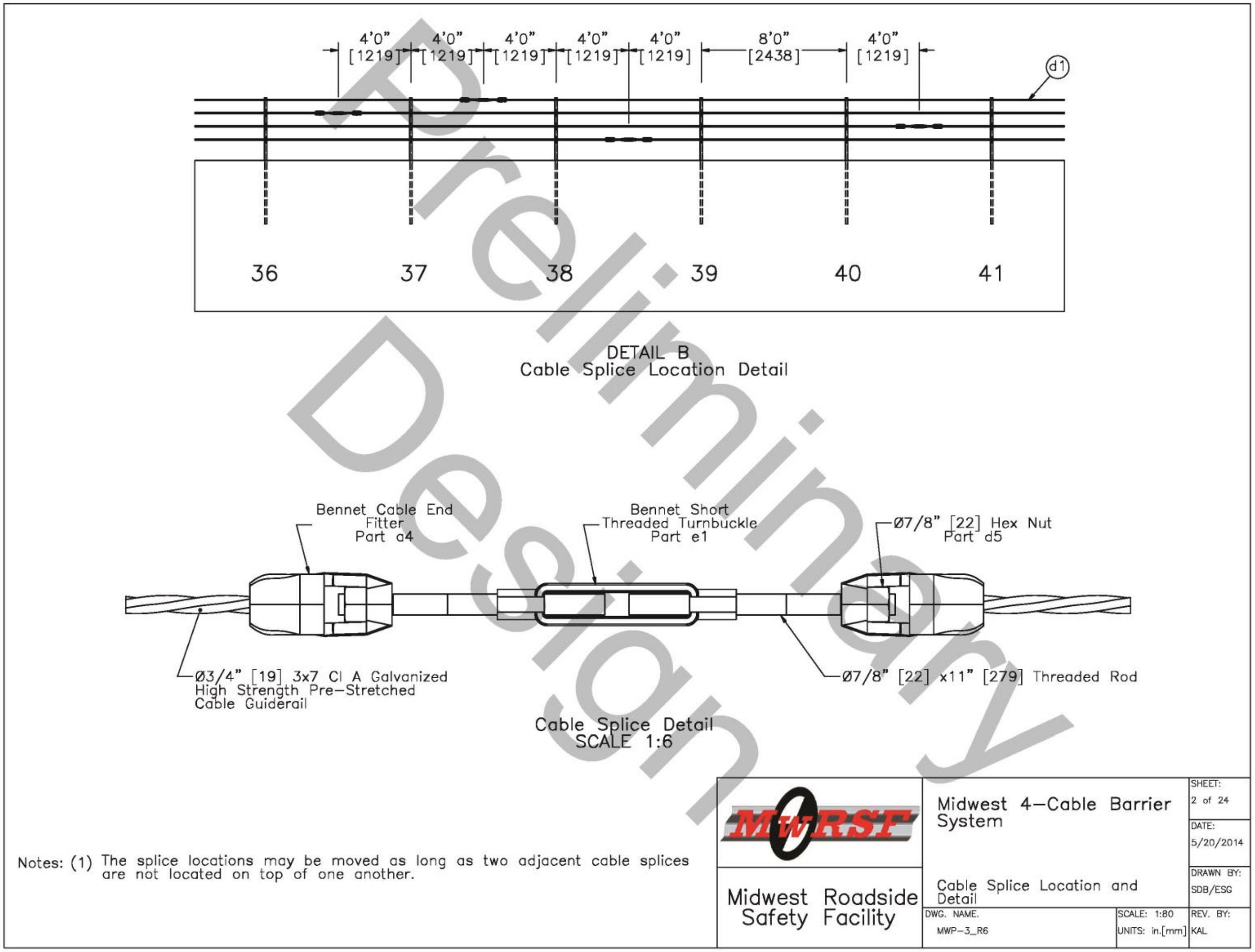


Figure 70. Cable Splice Location and Detail, Test No. MWP-3

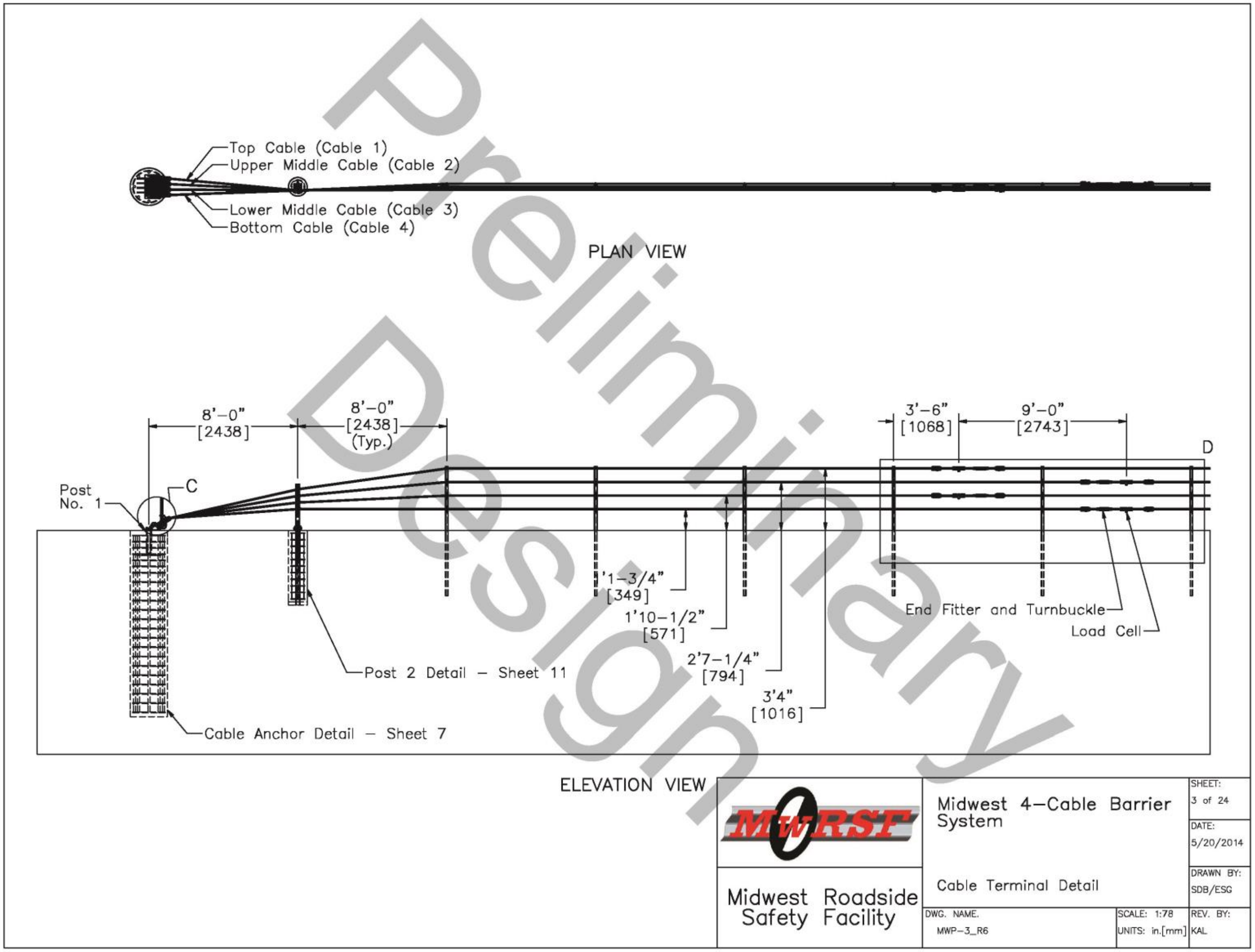


Figure 71. Cable Terminal Detail, Test No. MWP-3

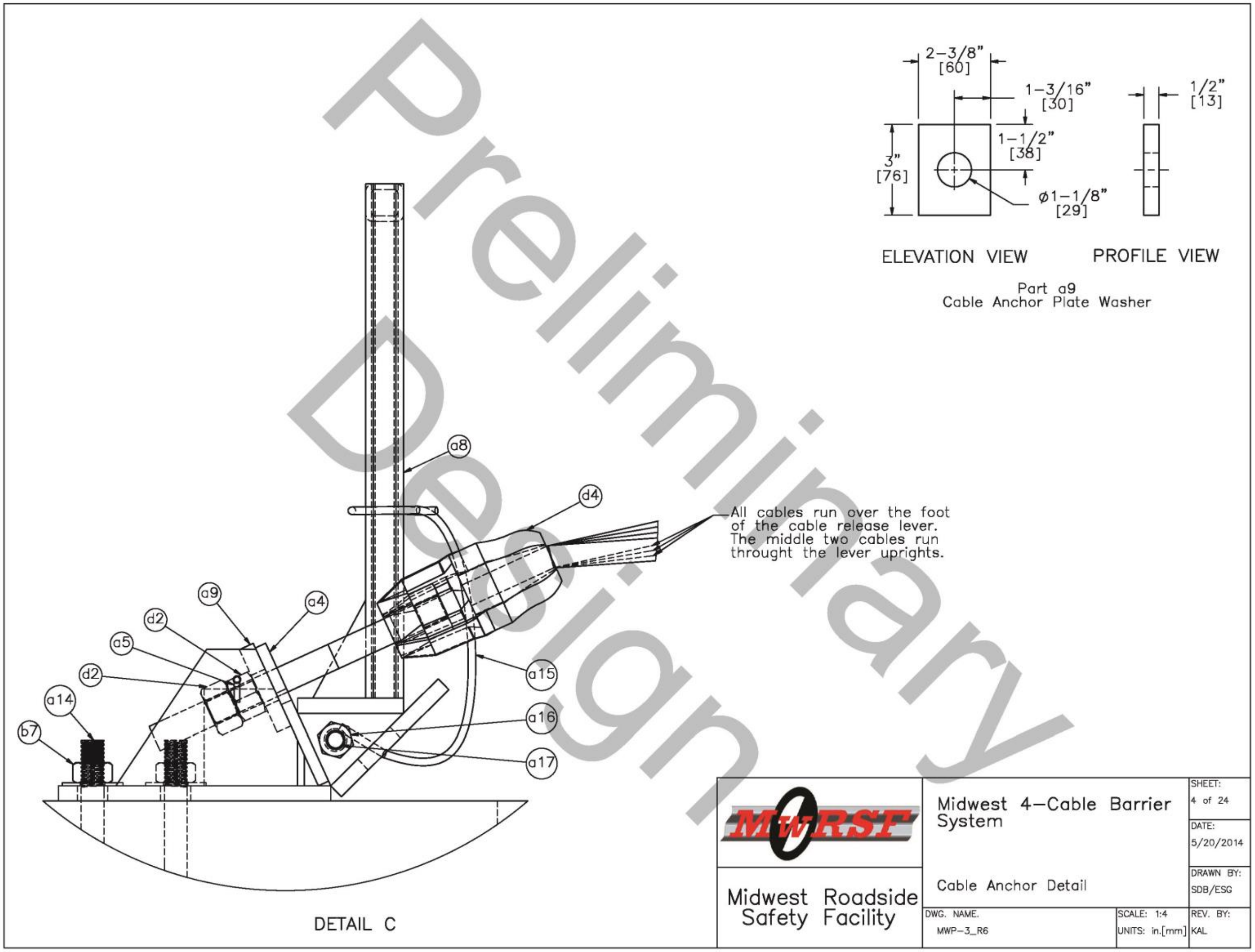


Figure 72. Cable Anchor Detail, Test No. MWP-3

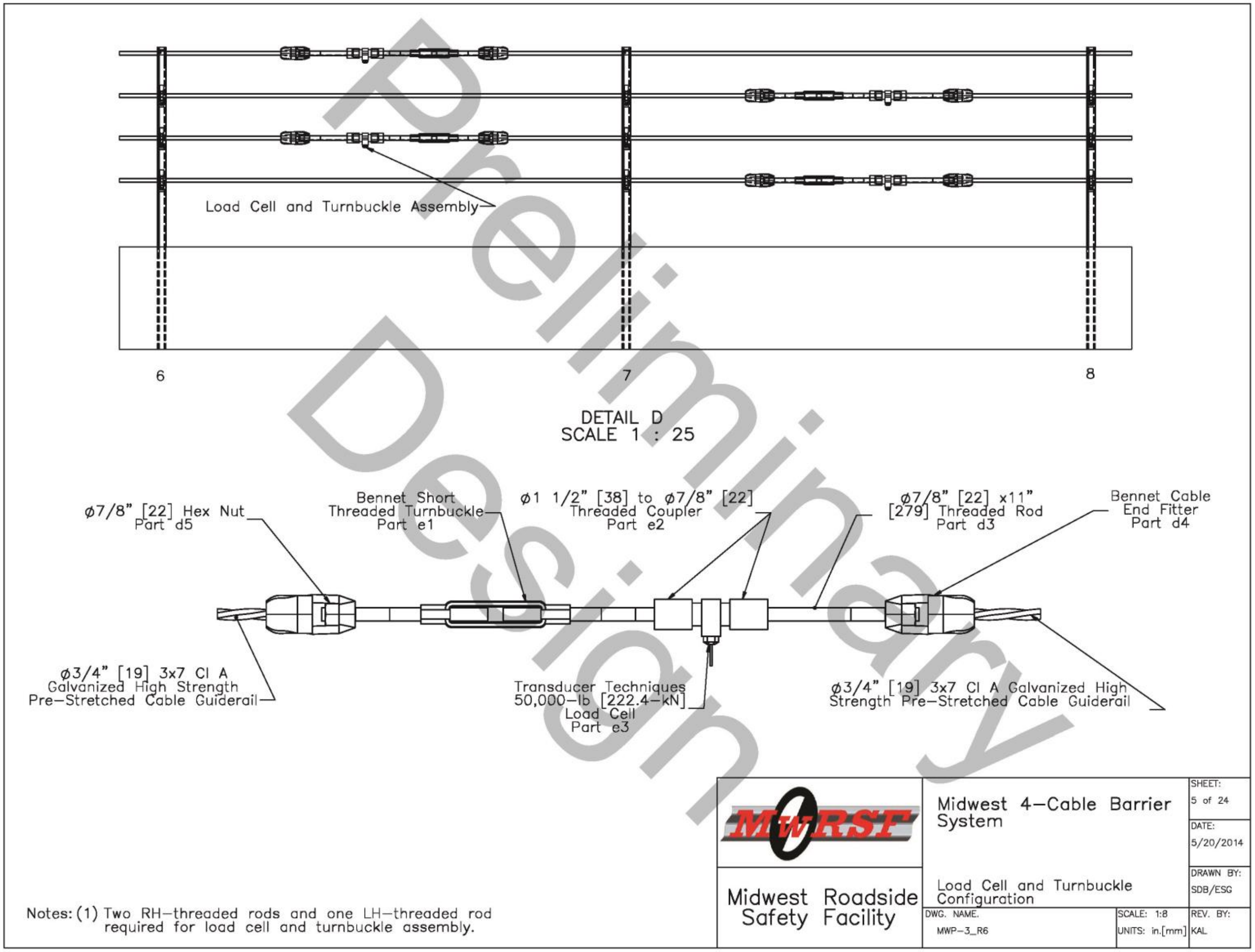


Figure 73. Load Cell and Turnbuckle Configuration, Test No. MWP-3

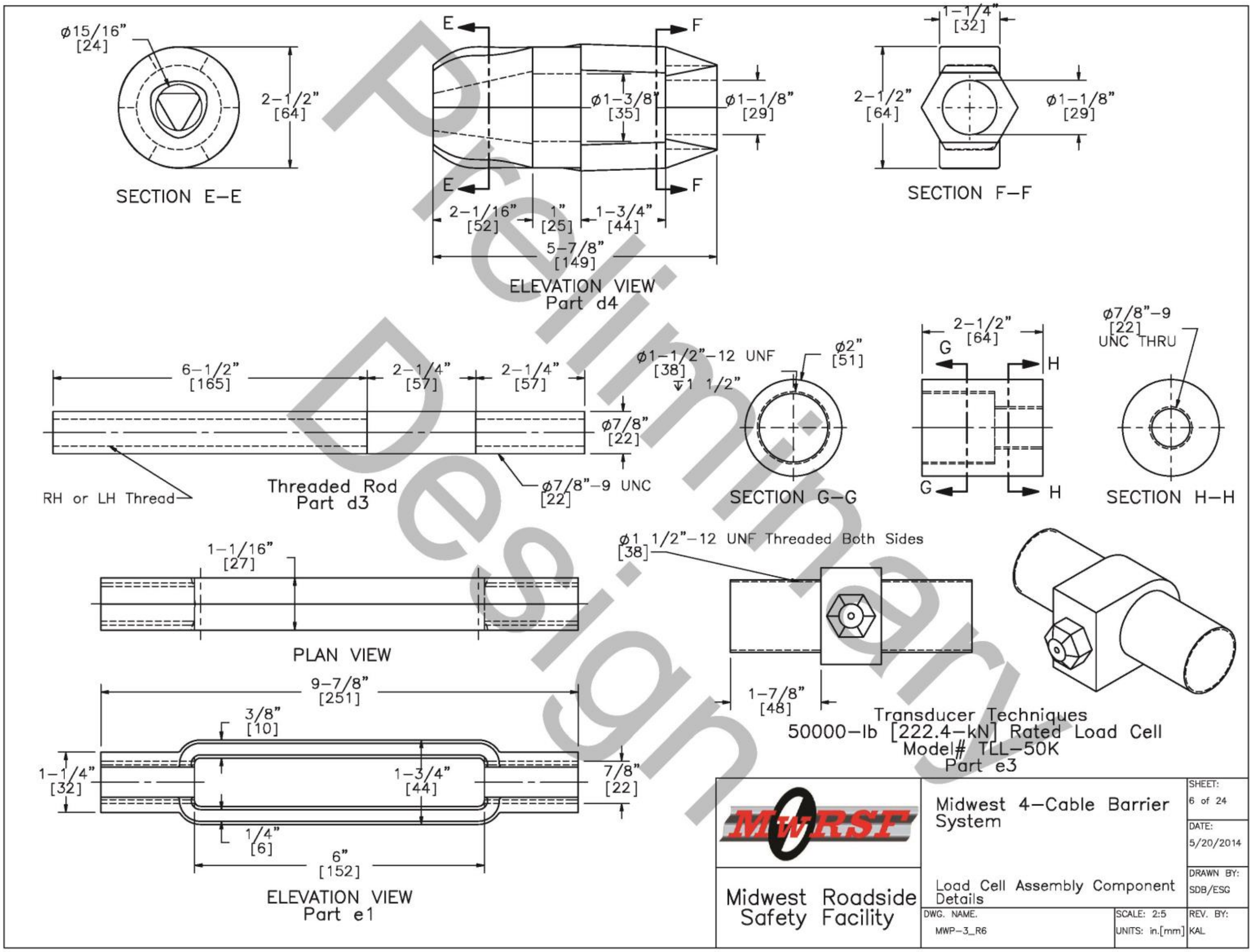


Figure 74. Load Cell Assembly Component Details, Test No. MWP-3

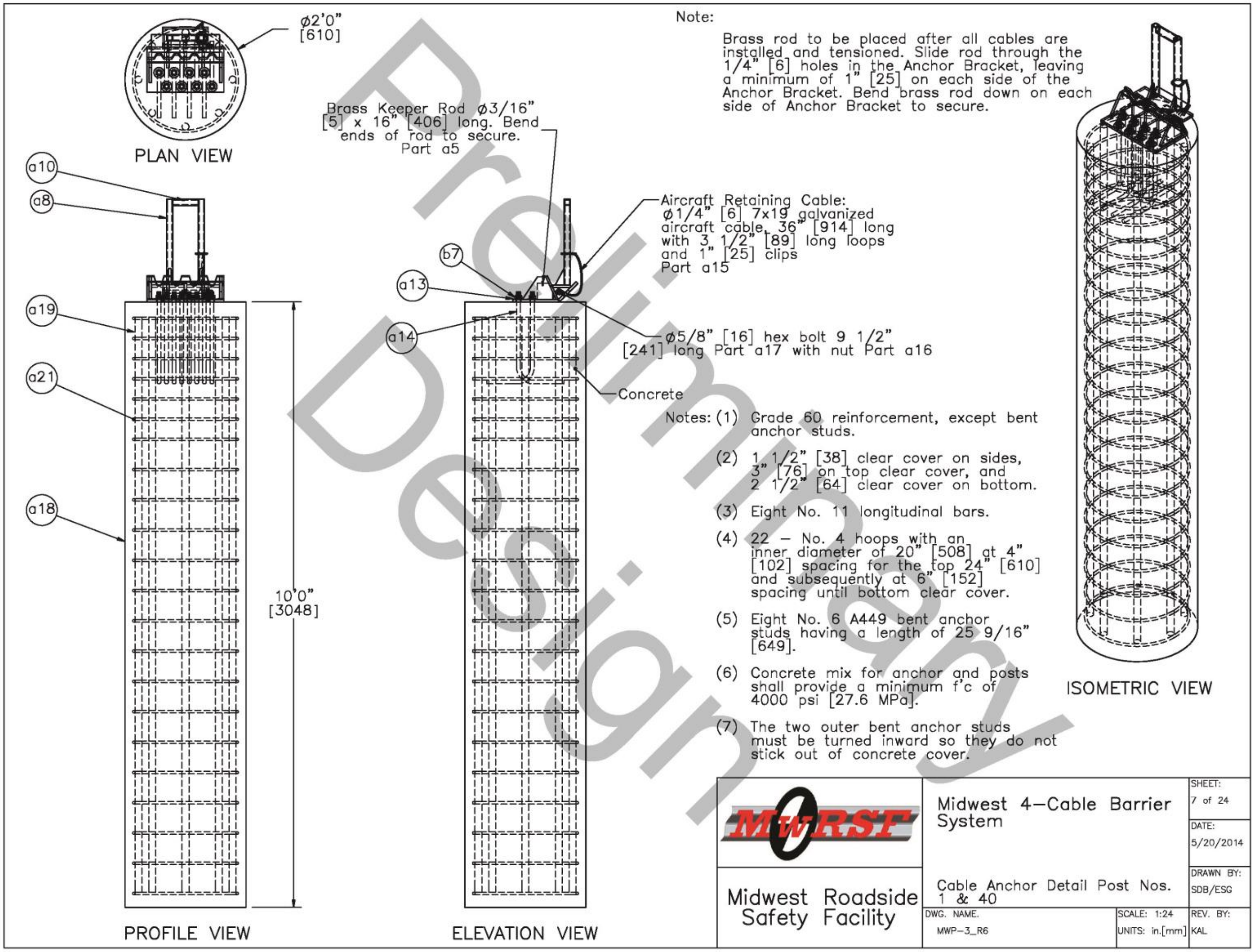


Figure 75. Cable Anchor Details, Post Nos. 1 and 40, Test No. MWP-3

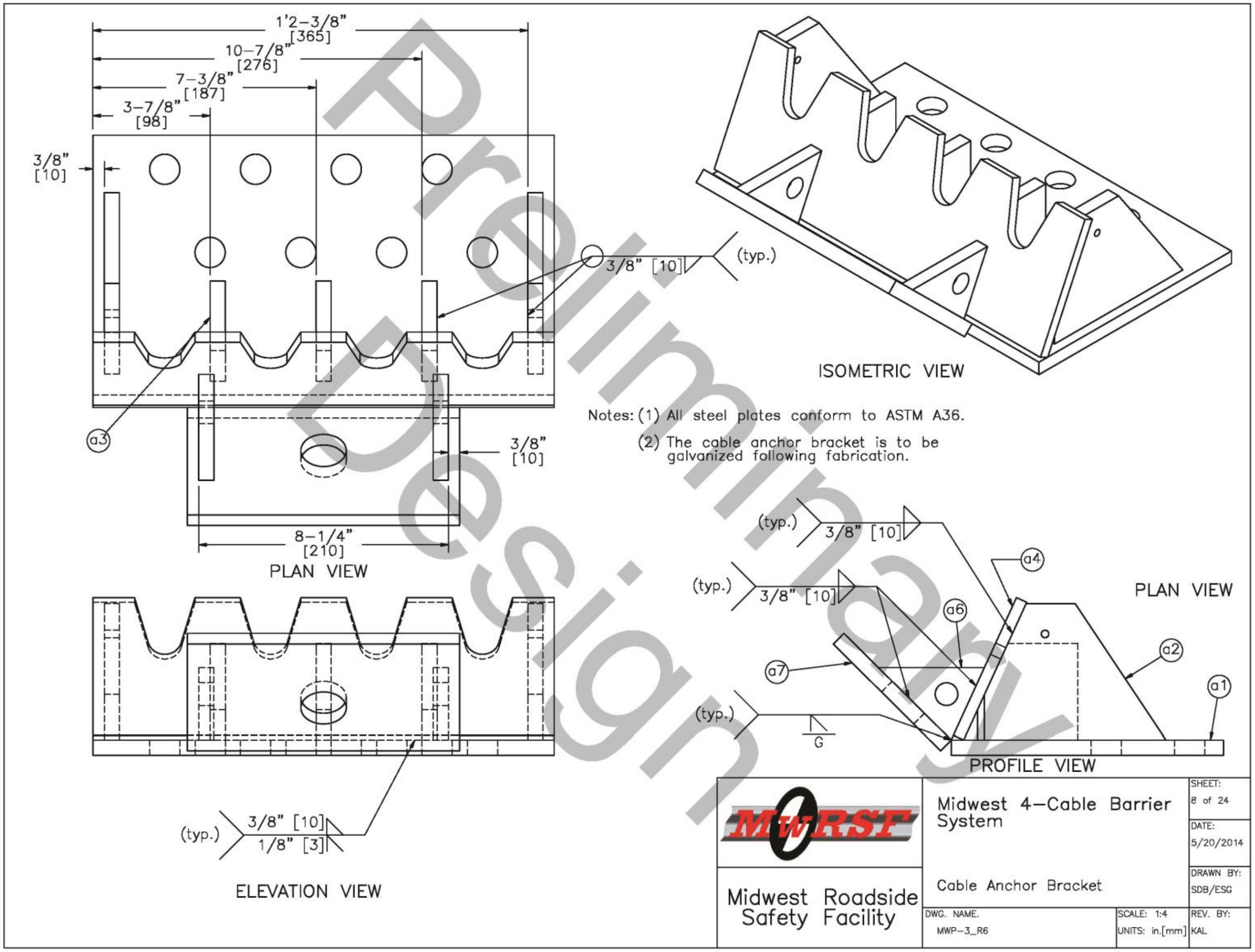


Figure 76. Cable Anchor Bracket, Test No. MWP-3

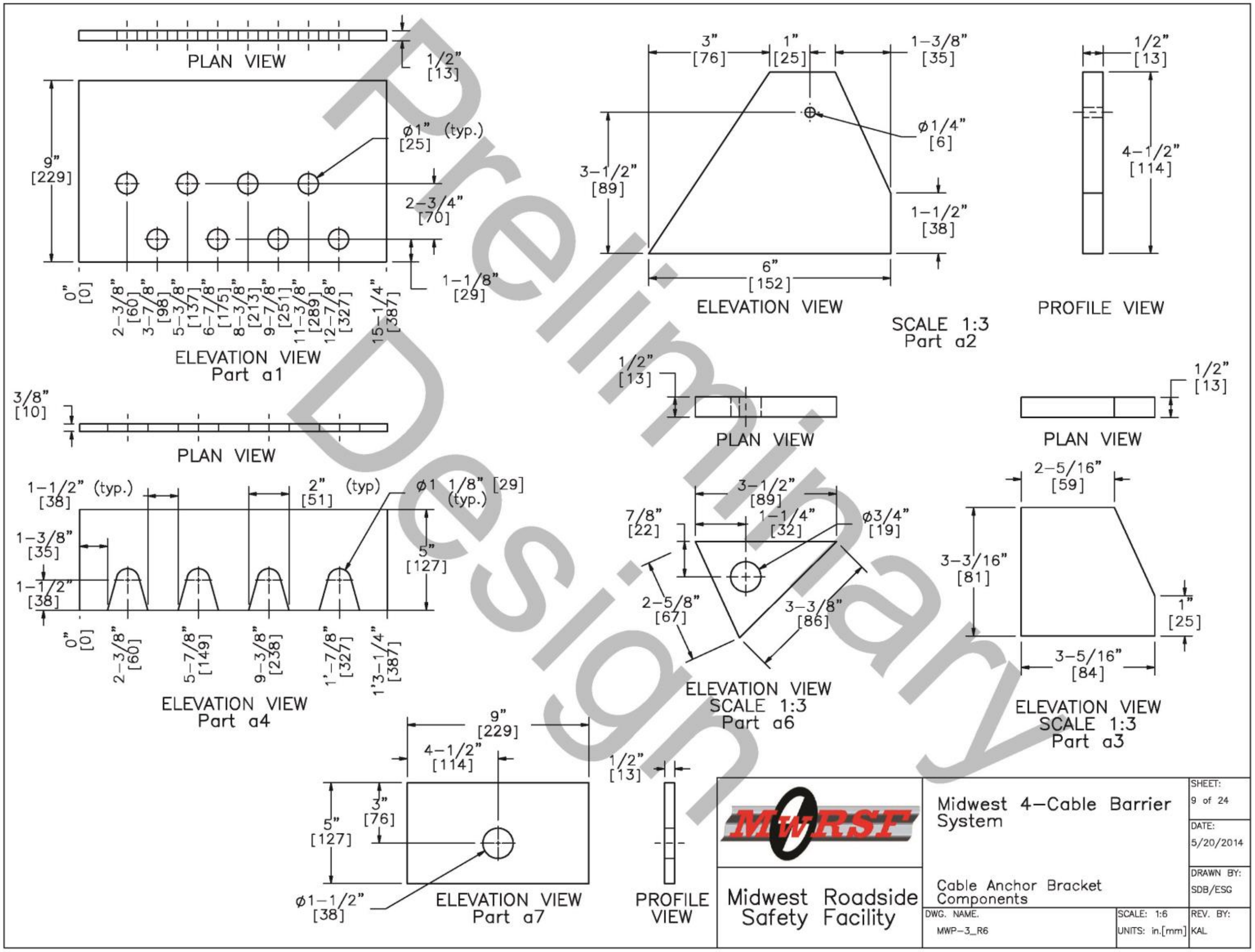


Figure 77. Cable Anchor Bracket Components, Test No. MWP-3

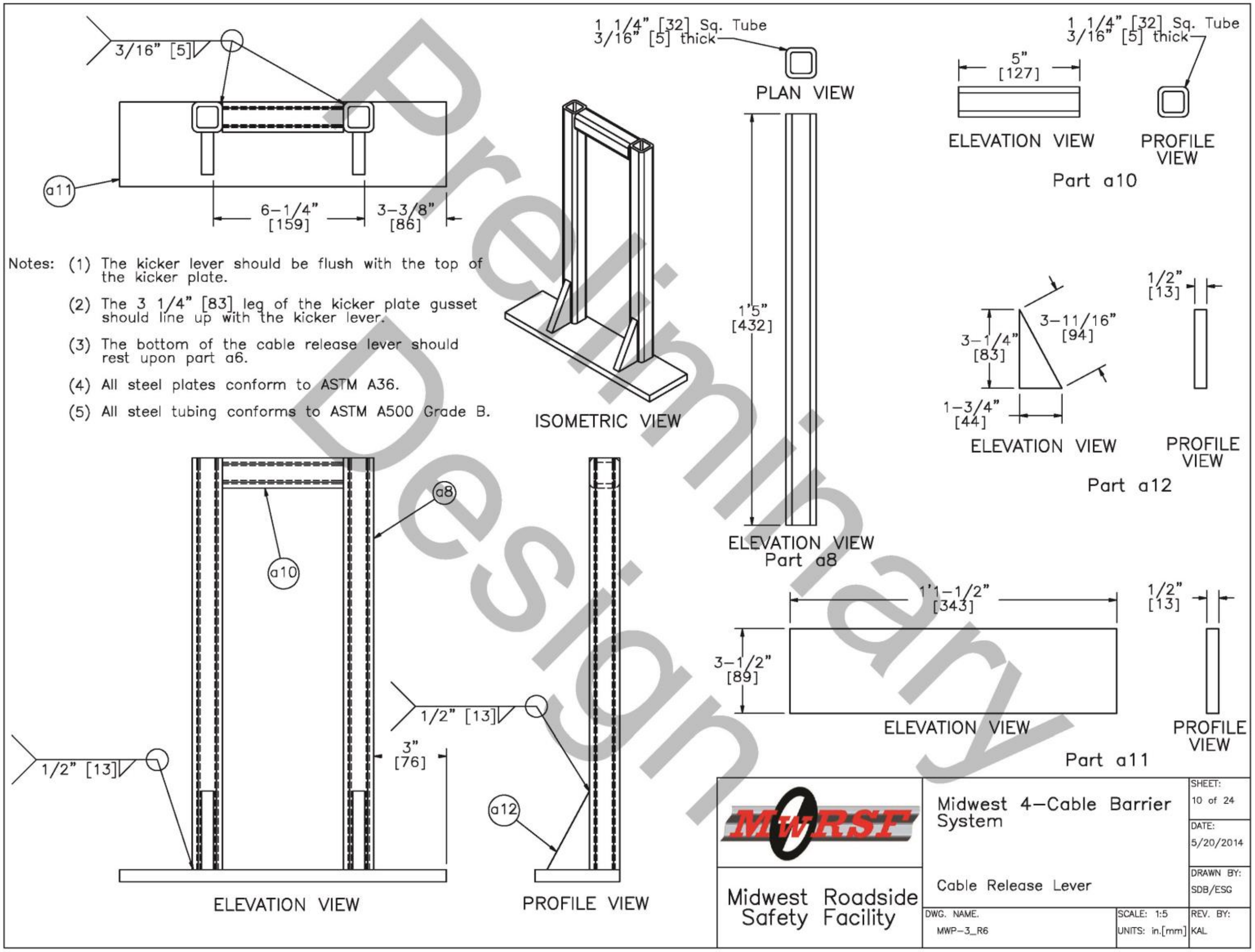


Figure 78. Cable Release Lever, Test No. MWP-3

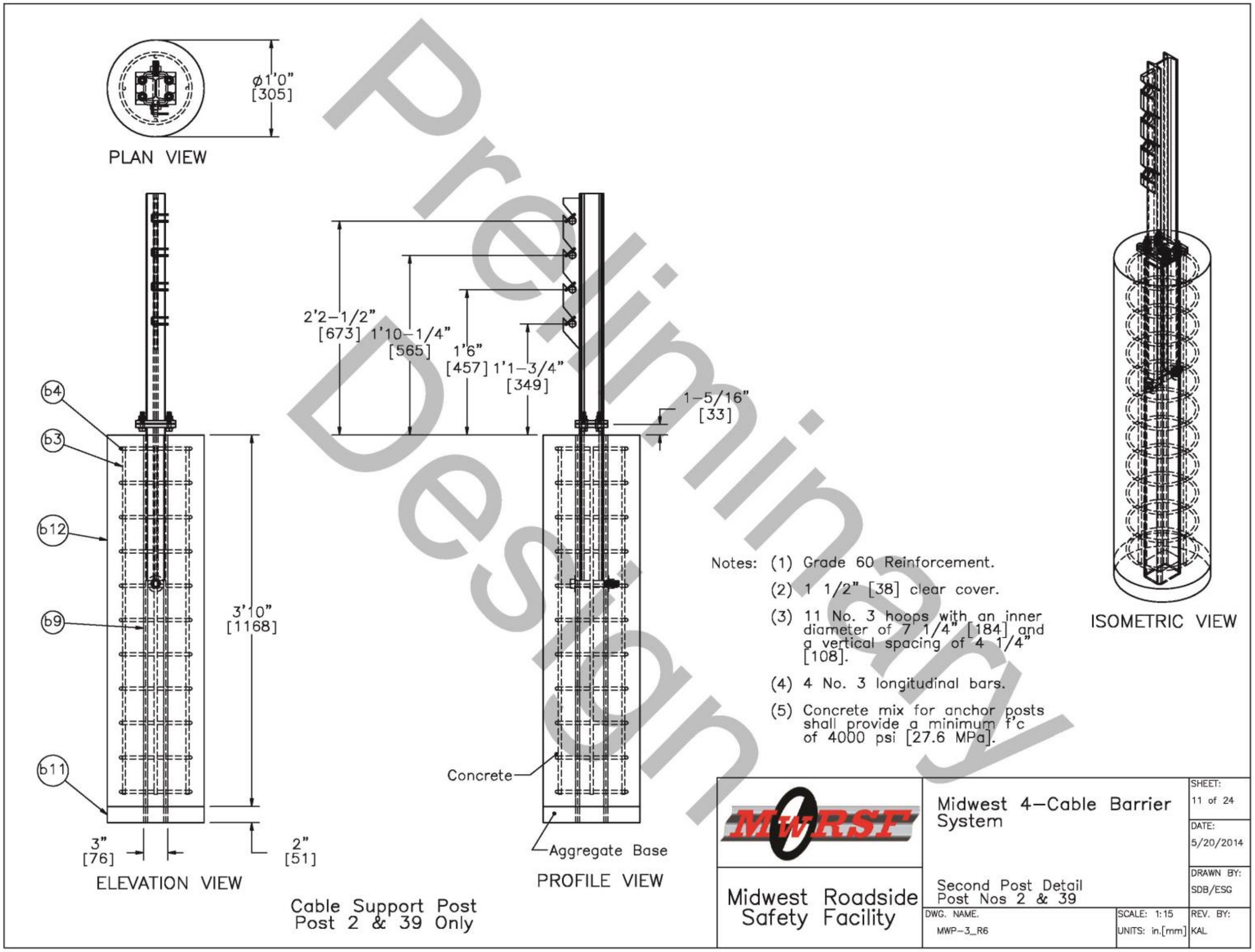


Figure 79. Second Post Details, Post Nos. 2 and 39, Test No. MWP-3

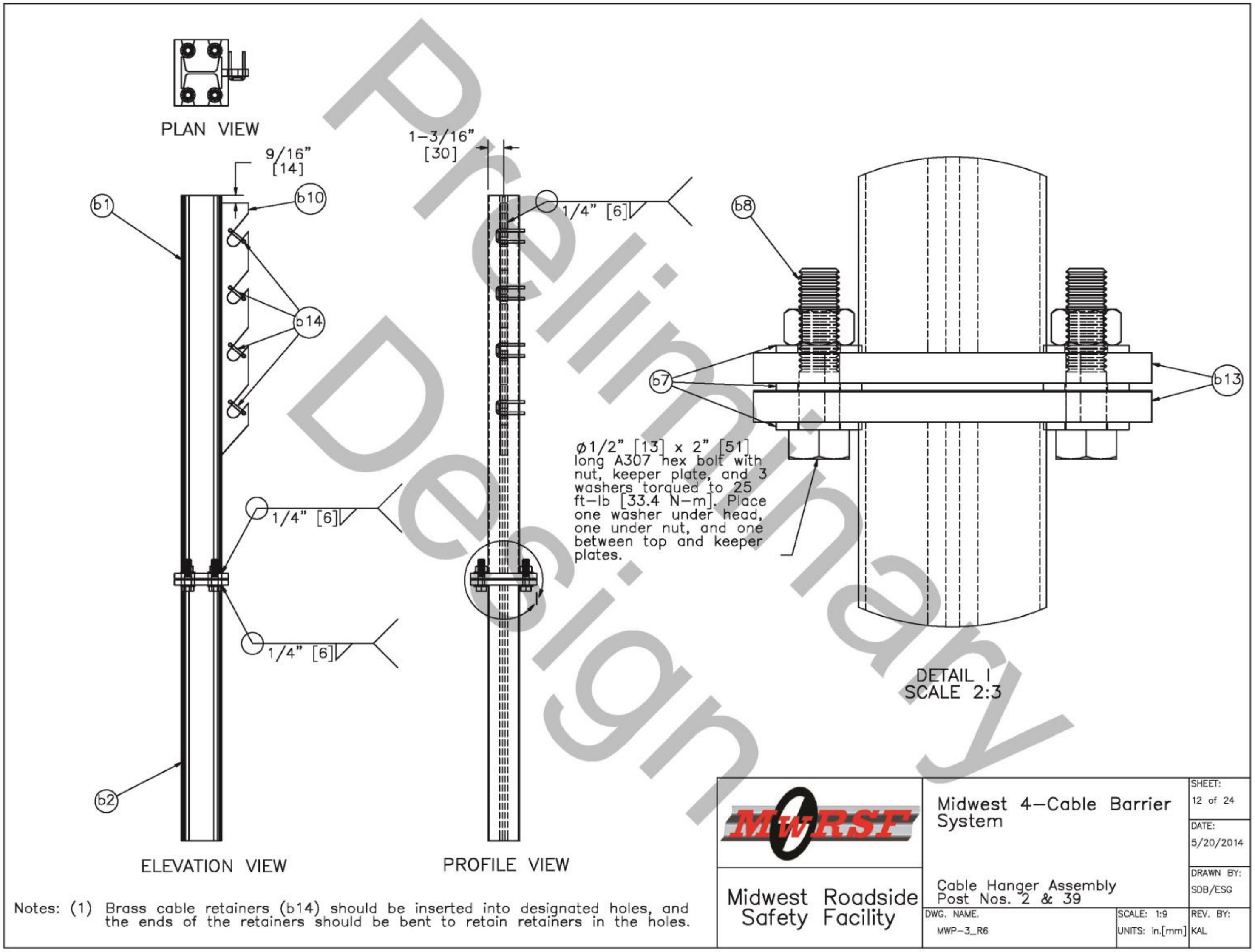


Figure 80. Cable Hanger Assembly, Post Nos. 2 and 39, Test No. MWP-3

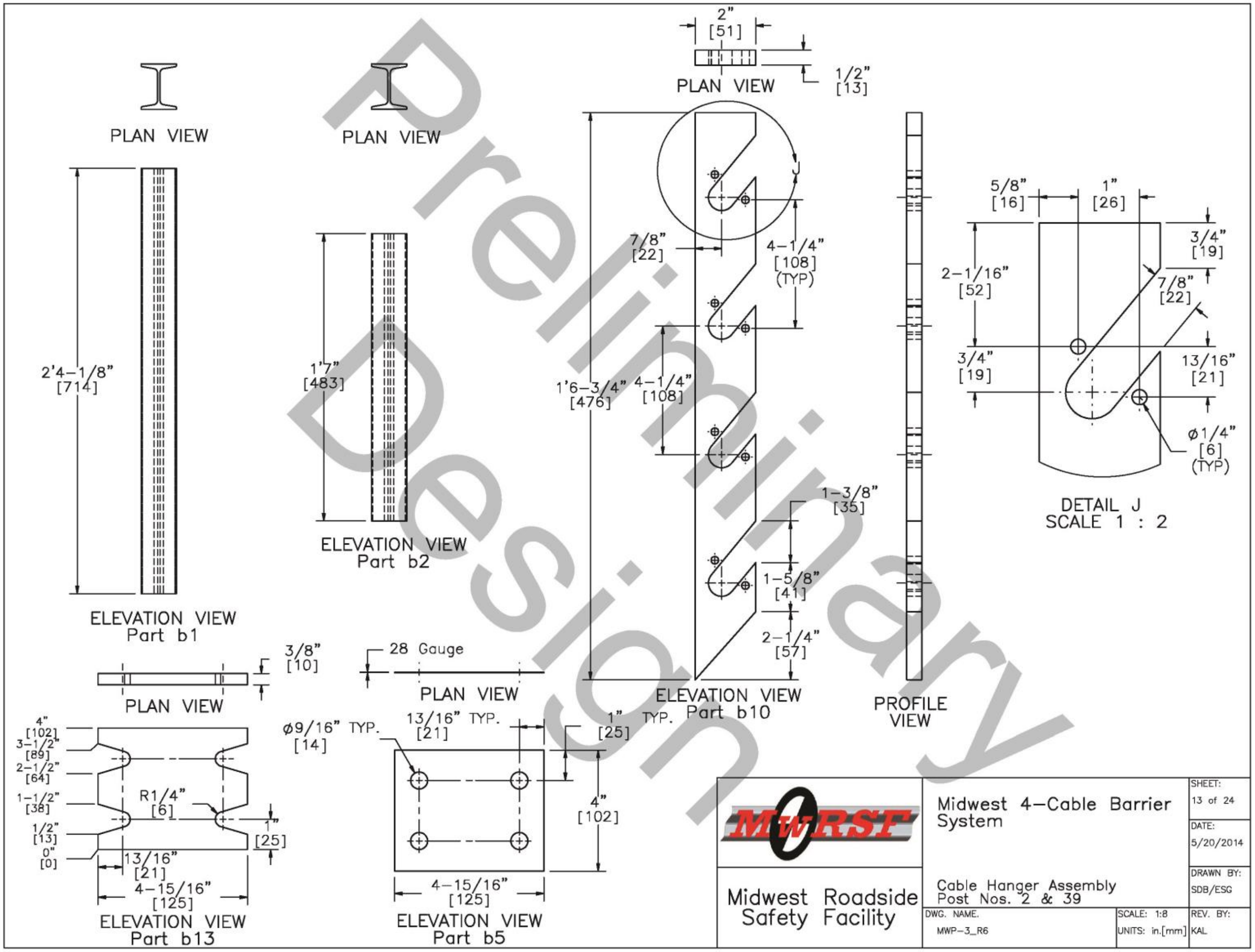


Figure 81. Cable Hanger Assembly, Post Nos. 2 and 39, Test No. MWP-3

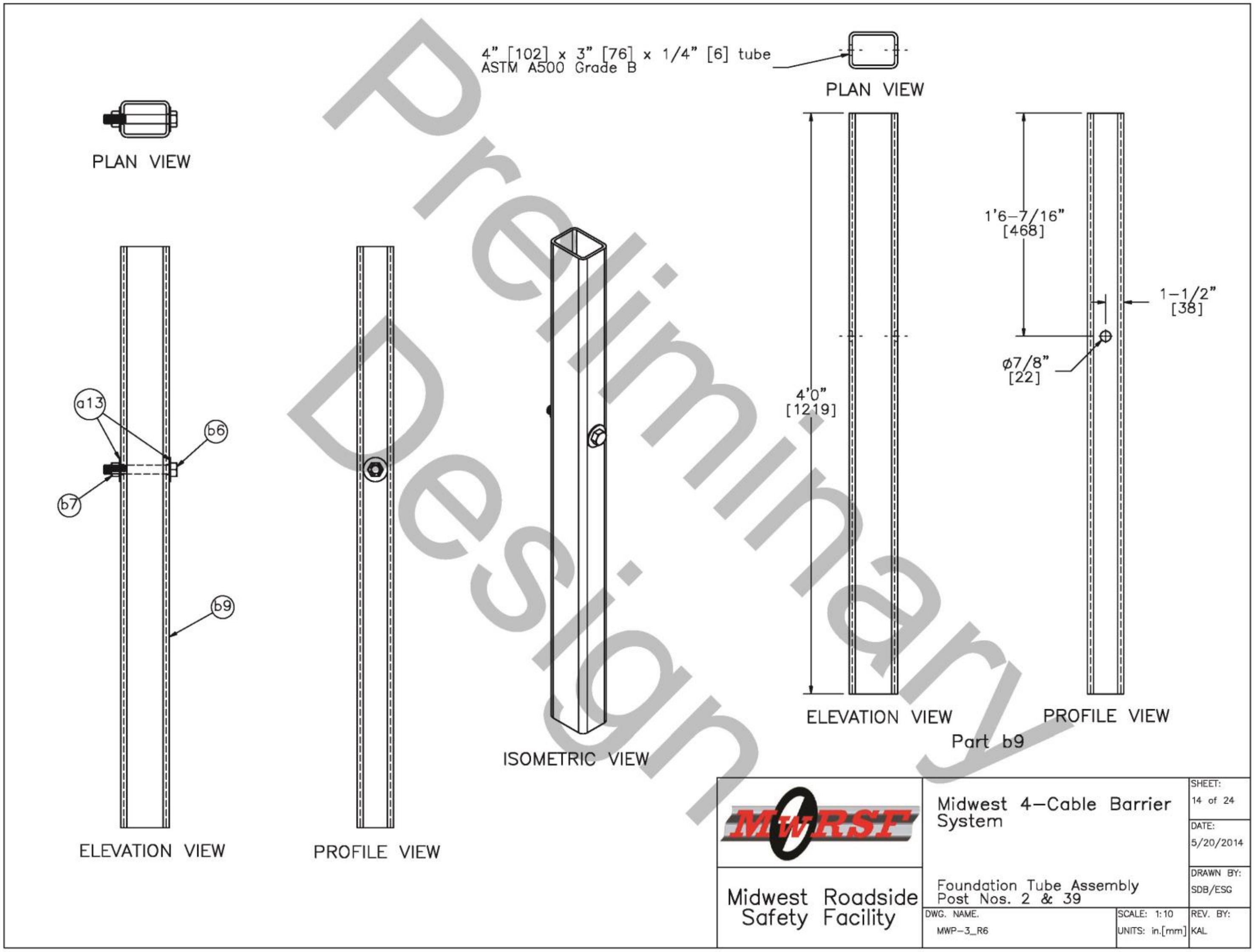


Figure 82. Foundation Tube Assembly, Post Nos. 2 and 39, Test No. MWP-3

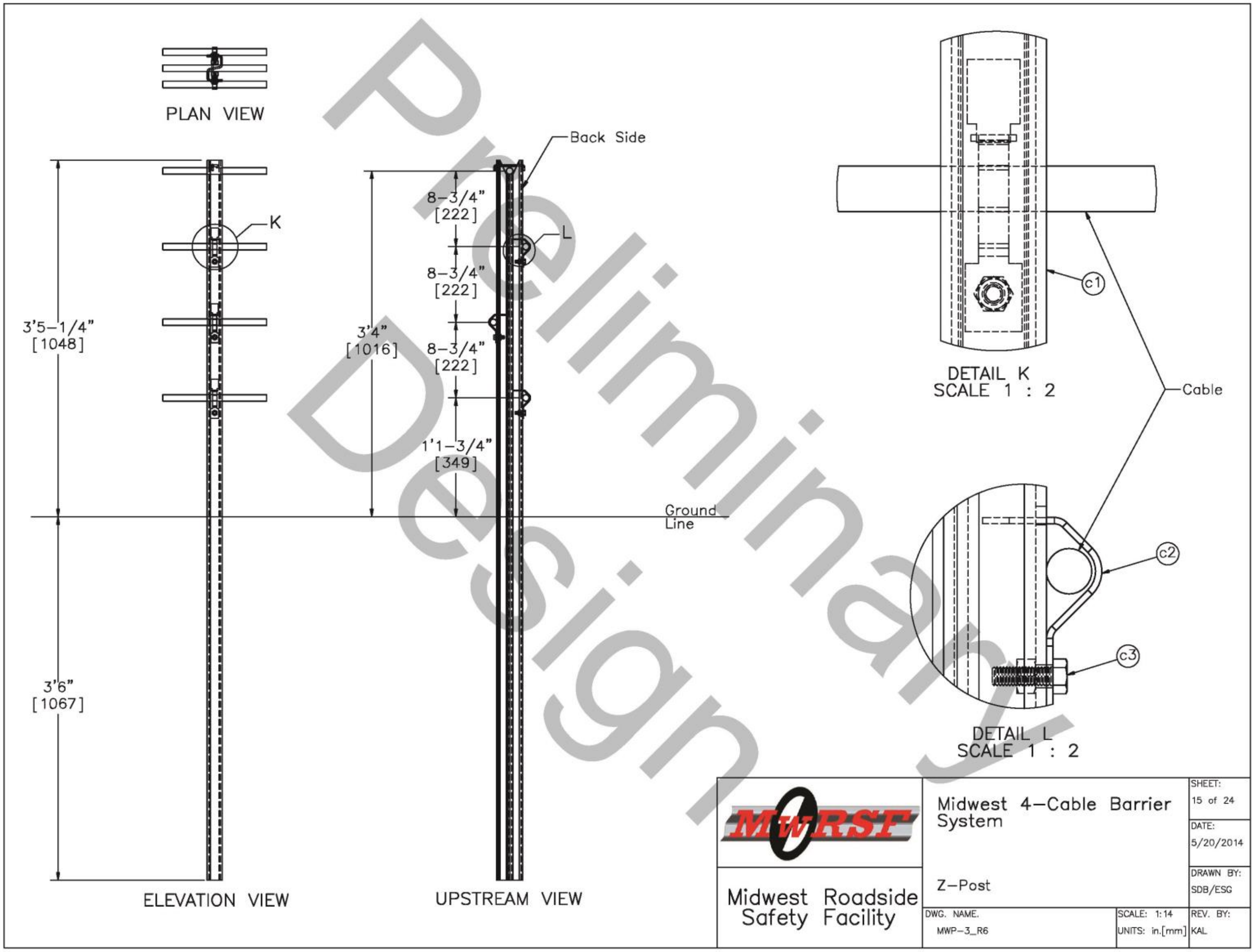


Figure 83. Z-Post Details, Test No. MWP-3

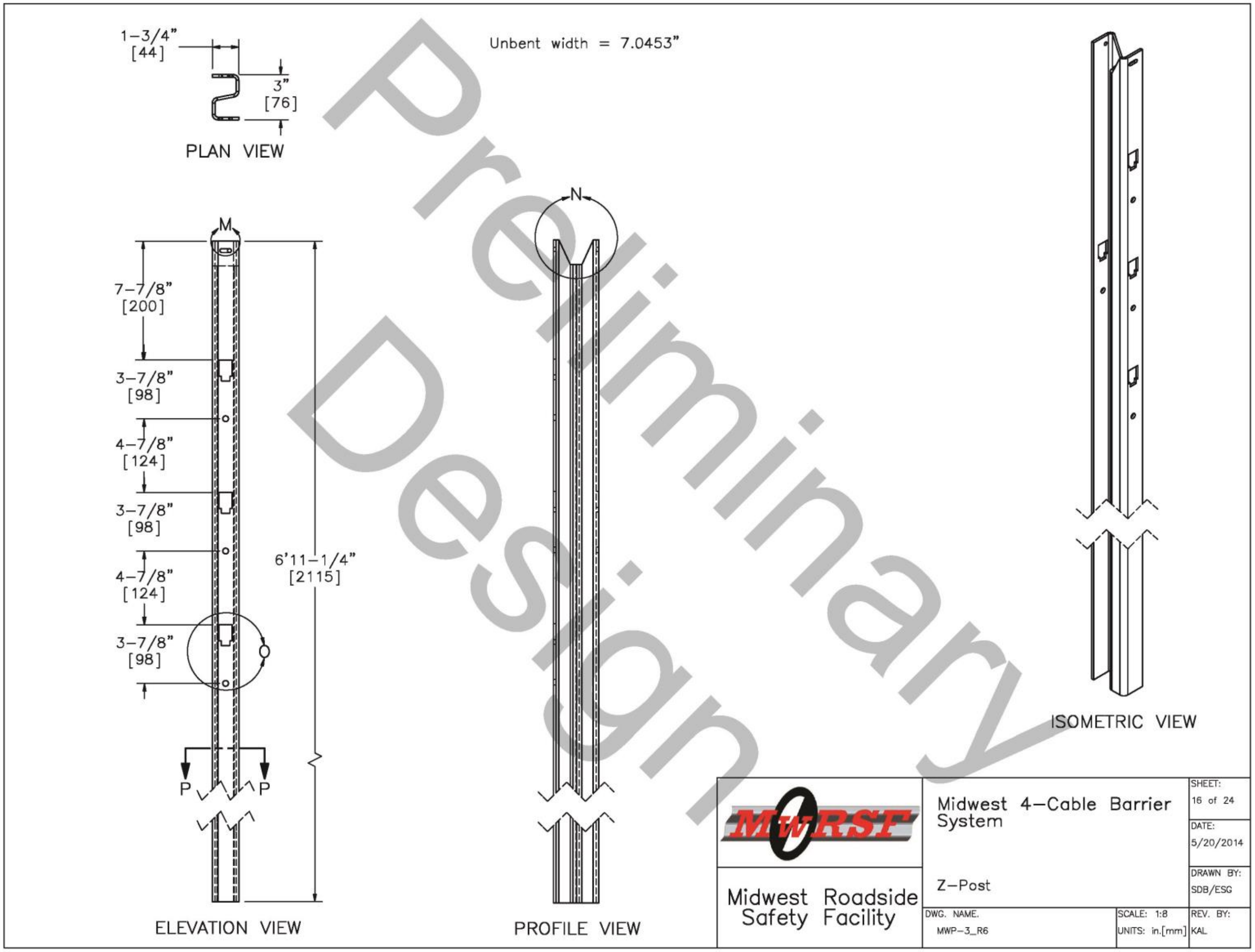


Figure 84. Z-Post Details, Test No. MWP-3

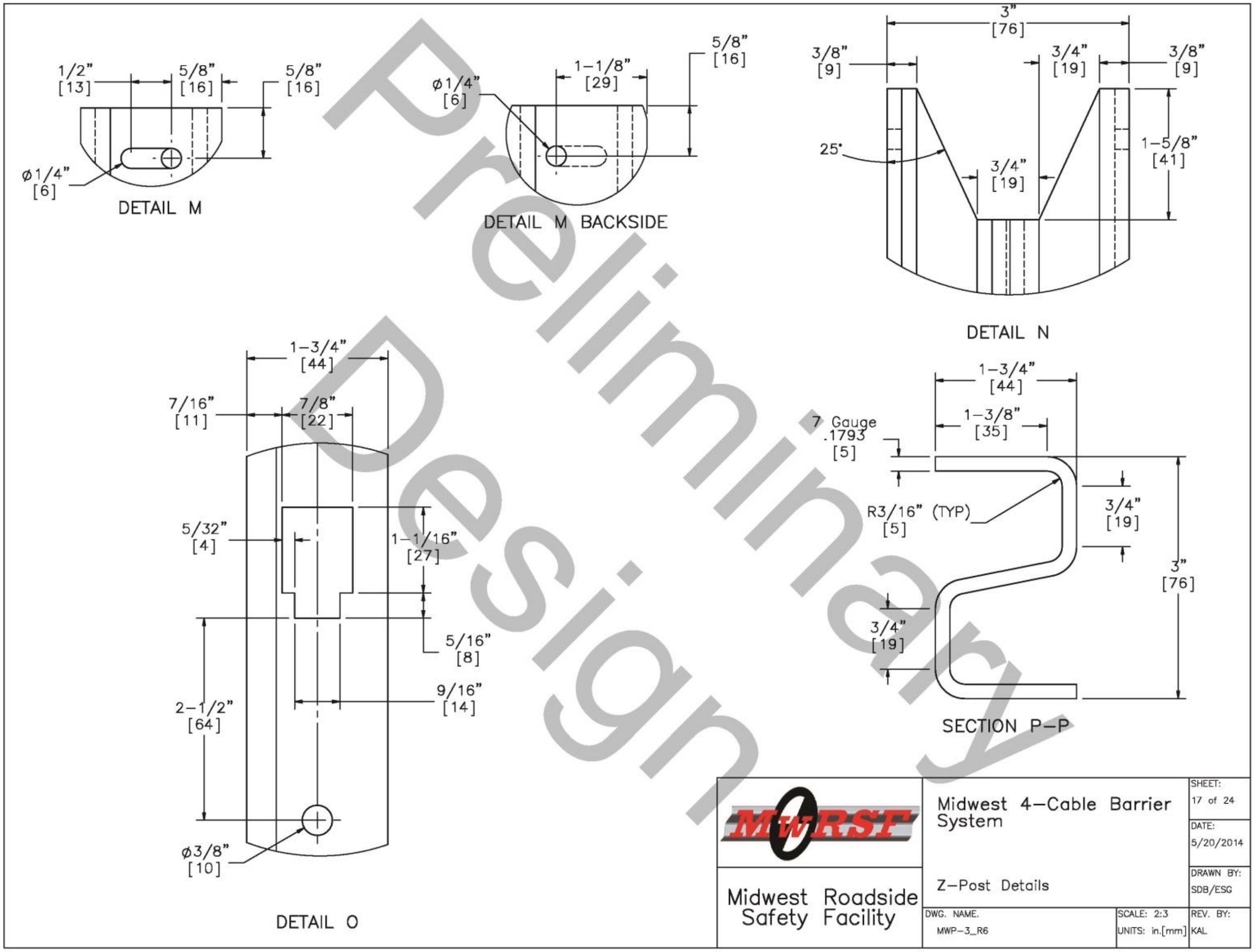


Figure 85. Z-Post Details, Test No. MWP-3

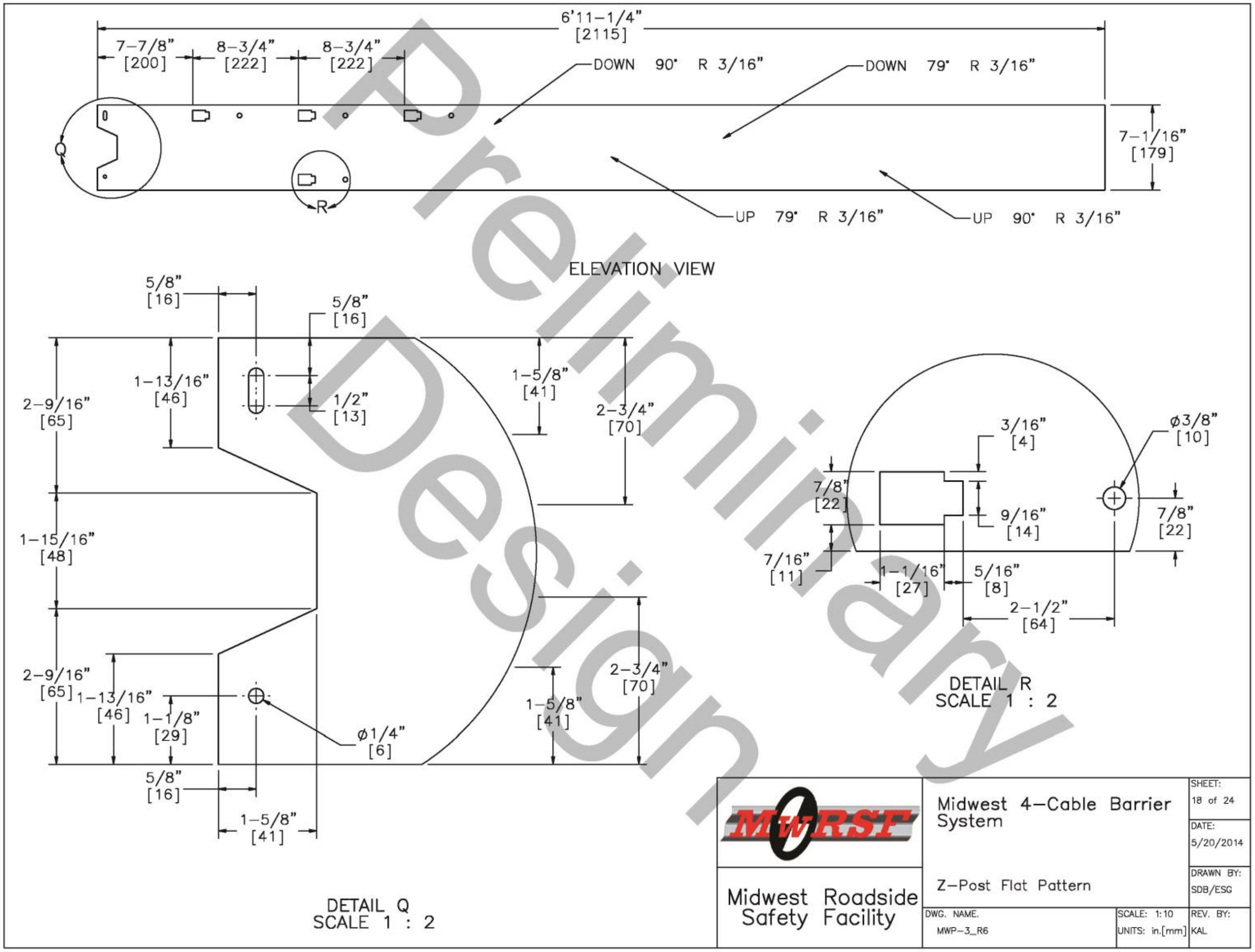


Figure 86. Z-Post Details, Flat Pattern, Test No. MWP-3

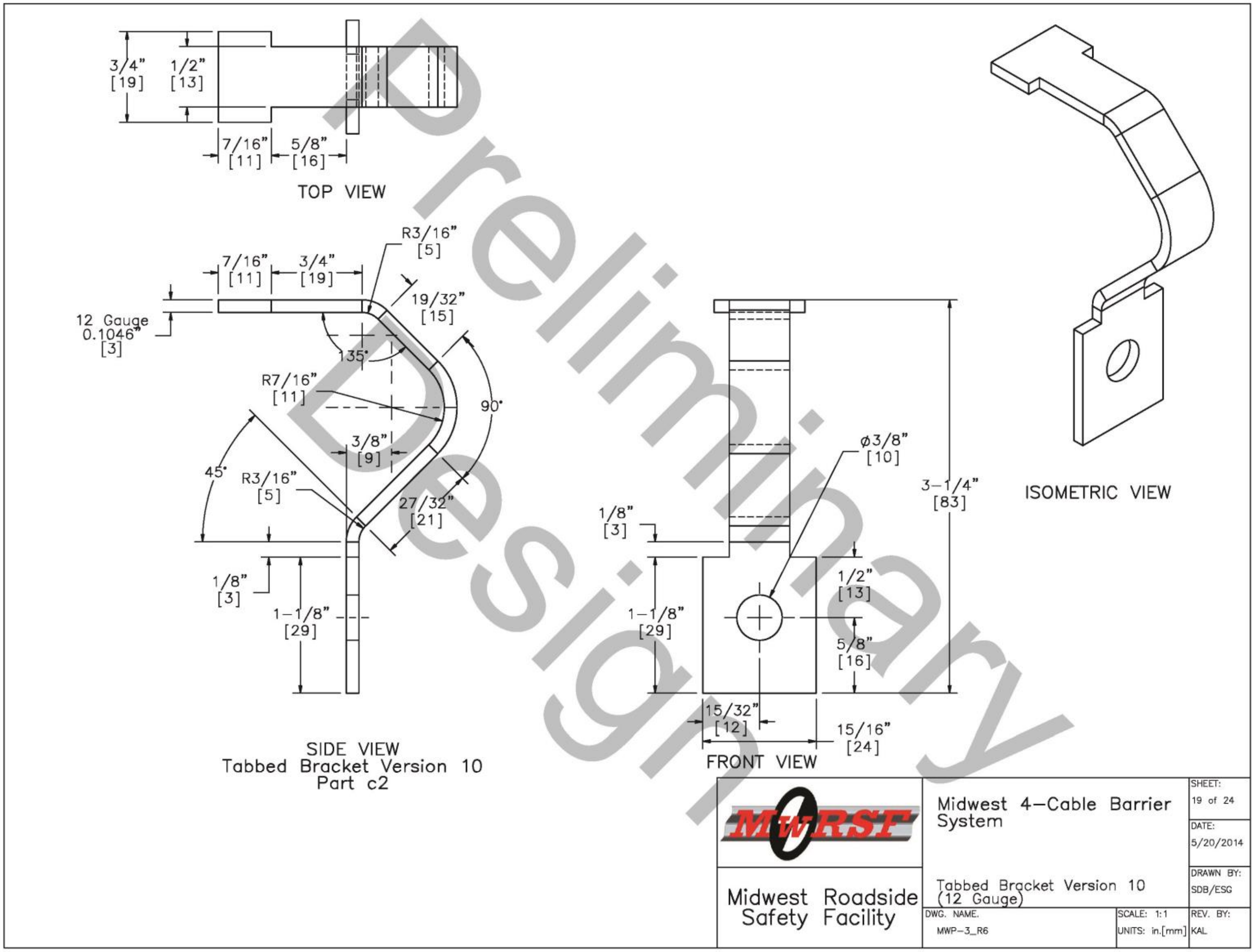


Figure 87. Tabbed Bracket Details, 12-Gauge, Test No. MWP-3

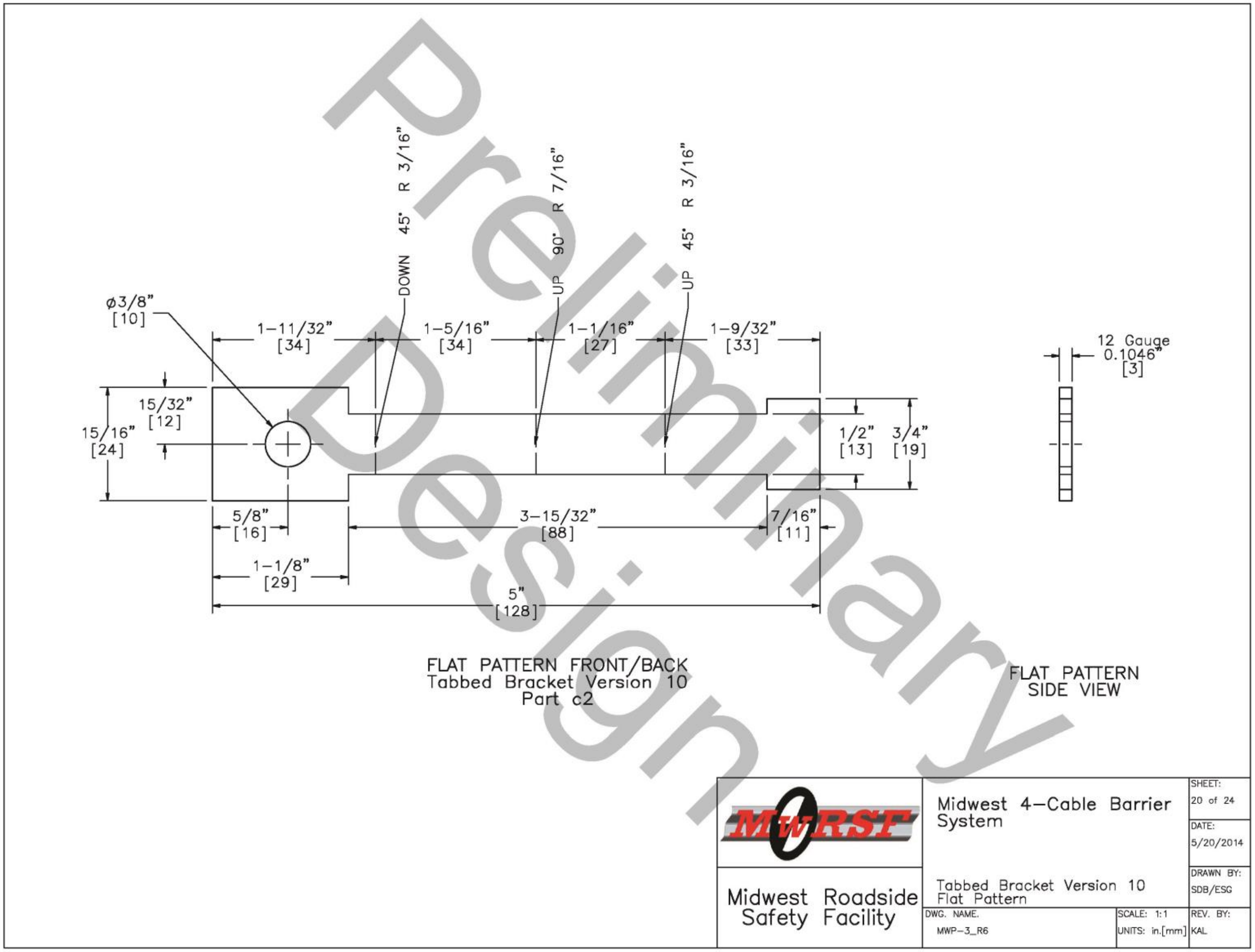


Figure 88. Tabbed Bracket Details, Flat Pattern, Test No. MWP-3

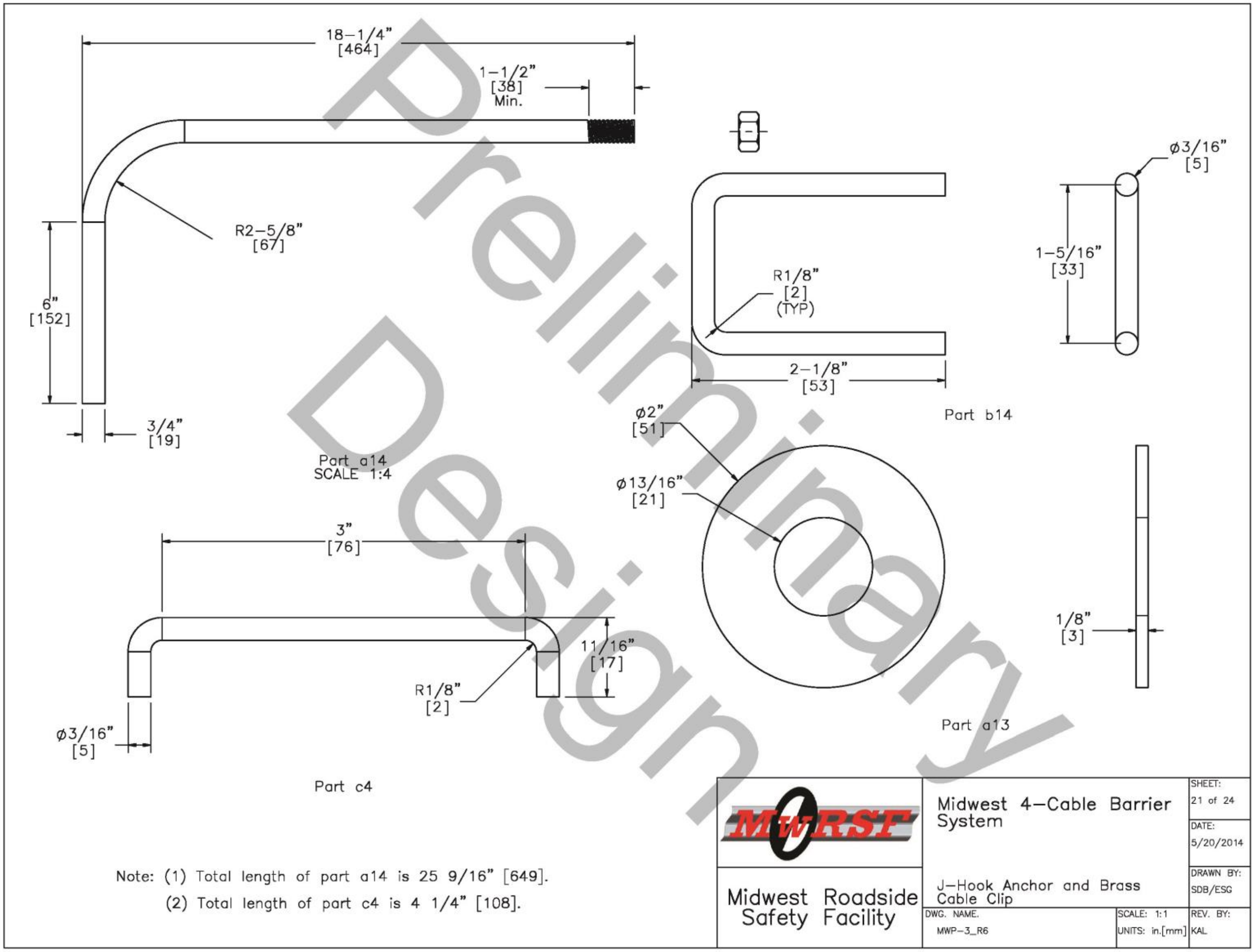


Figure 89. J-Hook Anchor and Brass Clips, Test No. MWP-3

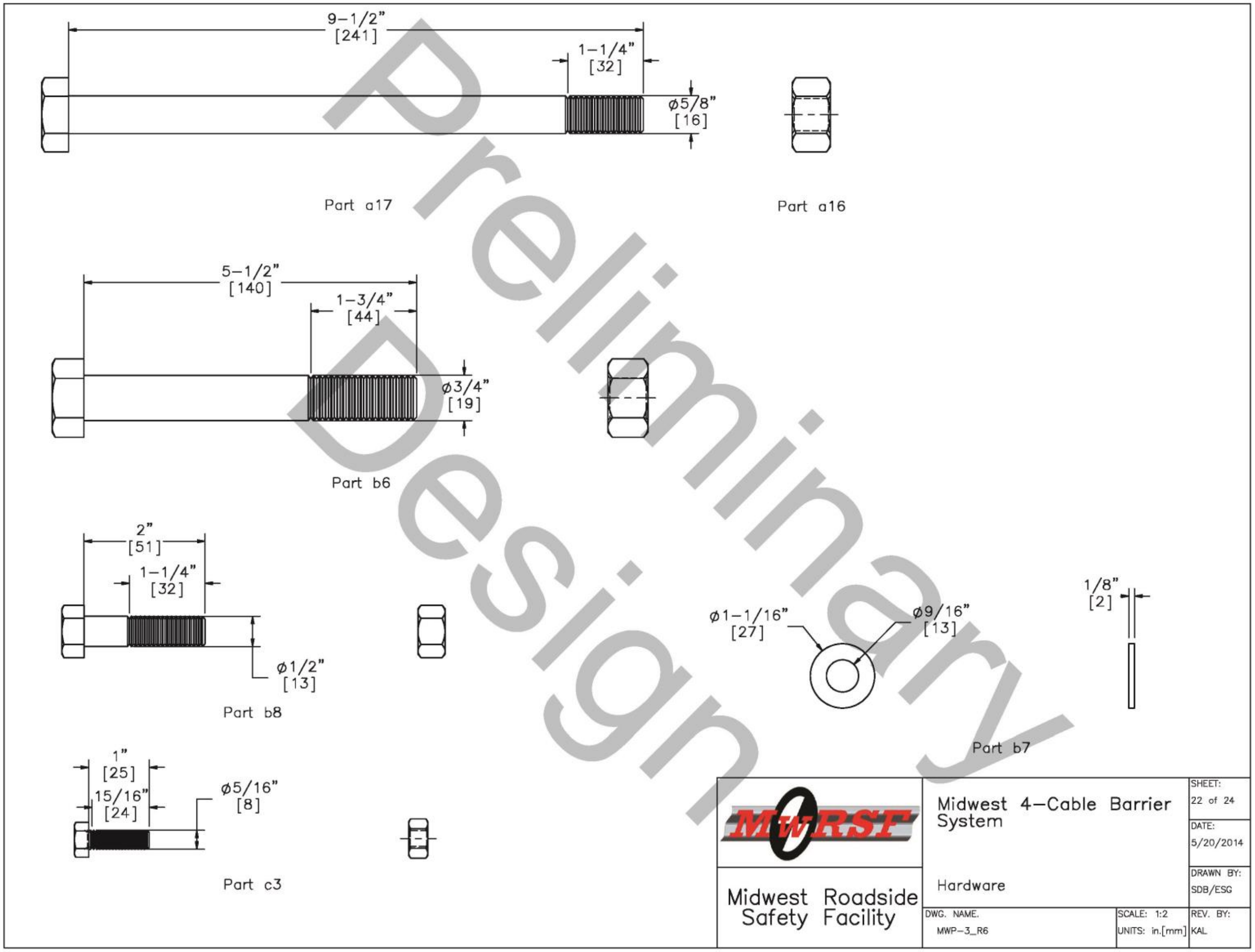


Figure 90. Hardware Details, Test No. MWP-3

Preliminary Design

Item No.	QTY.	Description	Material Specification
a1	2	Cable Anchor Base Plate	ASTM A36
a2	4	Exterior Cable Plate Gusset	ASTM A36
a3	6	Interior Cable Plate Gusset	ASTM A36
a4	2	Anchor Bracket Plate	ASTM A36
a5	2	3/16" [5] Dia. Brass Keeper Rod, 14" [356] long	Brass
a6	4	Release Gusset	A36 Steel
a7	2	Release Lever Plate	A36 Steel
a8	4	1.25x1.25x0.1875" [32x32x5] TS CT Kicker Lever Tube	ASTM A500 Gr. B
a9	8	CMB High Tension Anchor Plate Washer	ASTM A36
a10	2	1.25x1.25x0.1875" [32x32x5] TS CT Kicker Lever Connecting Tube	ASTM A 500 Gr. B
a11	2	3x10x0.5" [76x254x13] Kicker Plate	ASTM A36
a12	4	CT kicker – gusset	ASTM A36
a13	20	3/4" [19] Dia. Flat Washer	ASTM F844
a14	16	3/4" [19] Dia. UNC J–Hook Anchor and Hex Nut	J–Hook ASTM A449/Nut ASTM A563 DH
a15	2	1/4" [6] Dia. Aircraft Retaining Cable, 36" [914] long	7x19 Galv.
a16	2	5/8" [16] Dia. Heavy Hex Nut	ASTM A563C
a17	2	5/8" [16] Dia. UNC, 9 1/2" [241] Long Hex Bolt	ASTM A449 or SAE J429 Gr. 5
a18	2	24" [610] Dia. Concrete Anchor, 120" [3048] long	4,000 psi f'c
a19	16	#11 Straight Rebar, 114" [2896] long	Grade 60
a20	44	#4 Anchor Hoop Rebar with 21" [533] Dia.	Grade 60
b1	2	S3x5.7 [S76x8.5] Post by 28 1/8" [714]	ASTM A572 GR50–07, ASTM A709 GR50–09A, ASTM A992–06A
b2	2	S3x5.7 [S76x8.5] Post by 19" [483]	ASTM A572 GR50–07, ASTM A709 GR50–09A, ASTM A992–06A
b3	8	#3 Straight Rebar, 43" [1092] long	Grade 60
b4	22	7 1/4" [184] Dia. No. 3 Hoop Reinforcement	Grade 60
b5	2	2nd Post Keeper Plate, 28 Gauge	ASTM A36
b6	2	3/4" [19] Dia. UNC, 5 1/2" [140] Long Hex Bolt and Nut	Bolt ASTM A307 Gr. A/Nut ASTM A563A
b7	24	1/2" [13] Dia. Washer with 1 1/16" [27] OD	ASTM F844
b8	8	1/2" [13] Dia. UNC, 2" [51] long Hex Bolt and Nut	Bolt ASTM A307 Gr. A/Nut ASTM A563A
b9	2	4x3x1/4" [102x76x6] Foundation Tube, 48" [1168] long	ASTM A500 Grade B
b10	2	2nd Post Cable Hanger	ASTM A36
b11	2	2nd Post Anchor Aggregate 12 in, Depth	–
b12	2	12" Dia. 2nd Post Concrete Anchor, 46" long	4,000 psi f'c
b13	4	2nd Post Base Plate	ASTM A36
b14	8	3/16" [5] Dia. 5 1/4" [133] Long Brass Rod	ASTM B16–00

MwRSF
Midwest Roadside Safety Facility

Midwest 4–Cable Barrier System

Bill of Materials

SHEET: 23 of 24
DATE: 5/20/2014
DRAWN BY: SDB/ESG
DWG. NAME. MWP–3_R6
SCALE: NONE
UNITS: in.[mm]
REV. BY: KAL

Figure 91. Bill of Materials, Test No. MWP-3

Item No.	QTY.	Description	Material Spec
c1	72	3"x1-3/4"x7 Gauge [76x44x4.6], 83 1/4" [2115] Long Bent Z-Section Post	Hot-Rolled ASTM A1011 HSLA Gr. 50
c2	216	12 Gauge Tabbed Bracket - Version 10	Hot-Rolled ASTM A1011 HSLA Grade 50
c3	216	5/16" [8] Dia. UNC, 1" [25] Long Hex Cap Screw and Nut	Bolt SAE J429 Gr. 5 or ASTM A449/Nut ASTM A563 DH
c4	72	Straight Rod - ϕ3/16" [5] Cable Clip	ASTM B16 Brass C36000 Half Hard (HO2), ROUND. TS >= 68.0 ksi, YS >= 52.0 ksi
d1	1	3/4" [19] Dia. 3x7 Cable Guiderail	AASHTO M30-92(2000)/ASTM A741-98 Type 1 Class A coating except with Type 1 minimum breaking strength = 39 kips [173.5 kN]
d2	16	7/8" [22] Dia. Hex Nut	ASTM A563C
d3	28	Cable End Threaded Rod	ASTM A449
d4	24	Bennet Cable End Fitter	ASTM A47
d5	24	7/8" [22] Dia. Hex Nut	SAE J429 Gr. 5
e1	8	Bennet Short Threaded Turnbuckle	Not Specified
e2	8	Threaded Load Cell Coupler	N/A
e3	4	50,000-lb [222.4-kN] Load Cell	N/A

Preliminary Design

Midwest Roadside Safety Facility	Midwest 4-Cable Barrier System		SHEET: 24 of 24 DATE: 5/20/2014
	Bill of Materials		DRAWN BY: SDB/ESG
	DWG. NAME. MWP-3_R6	SCALE: NONE UNITS: in.[mm]	REV. BY: KAL

Figure 92. Bill of Materials, Test No. MWP-3

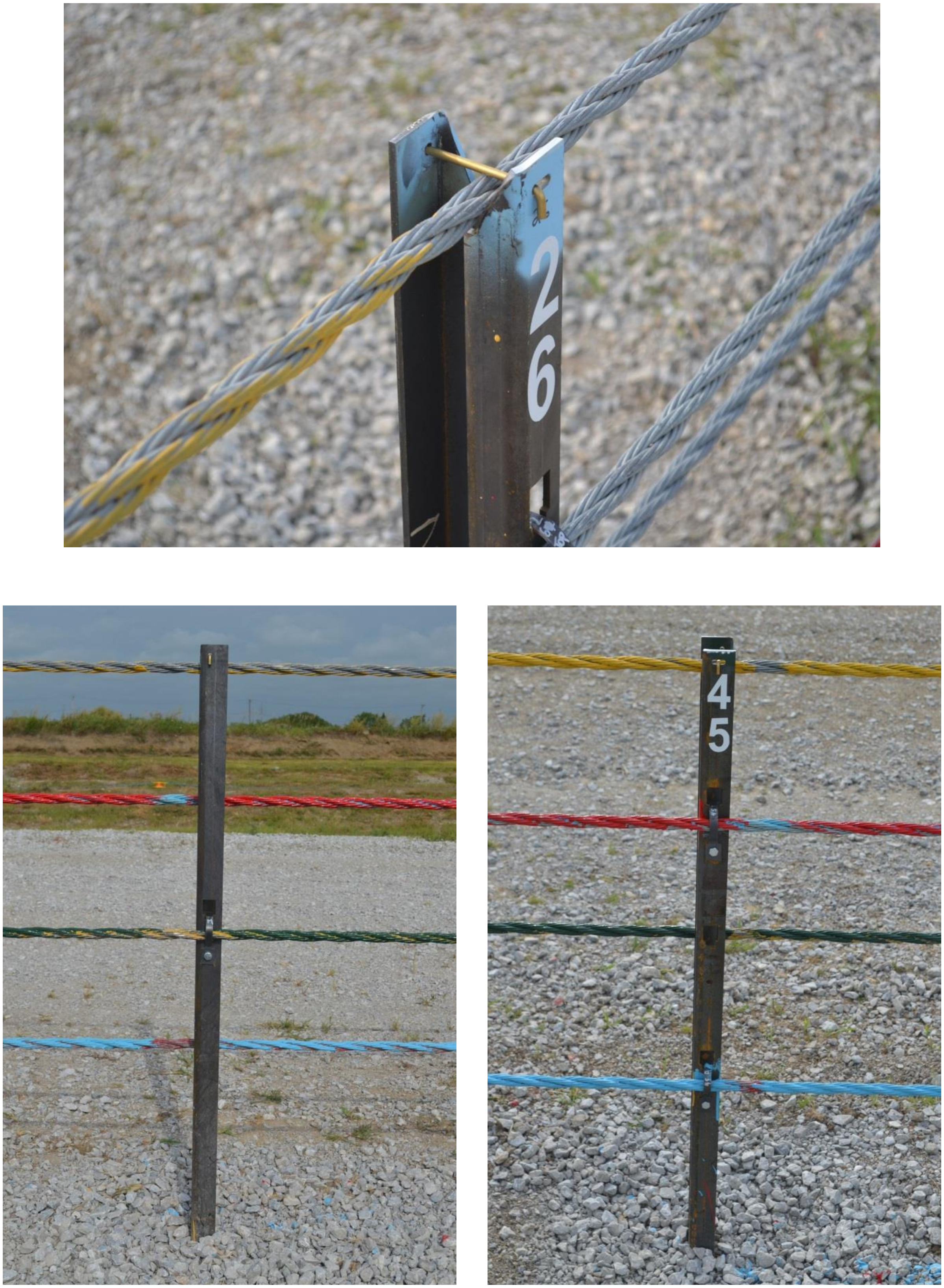


Figure 93. Test Installation Photographs, Test No. MWP-3

9 FULL-SCALE CRASH TEST NO. MWP-3

9.1 Static Soil Test

Before full-scale crash test no. MWP-3 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH. The static test results, as shown in Appendix C, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

9.2 Test No. MWP-3

The 4,992-lb (2,264-kg) pickup truck impacted the high-tension four cable median barrier at a speed of 60.0 mph (96.6 km/h) and an angle of 26.3 degrees. A summary of the test results and sequential photographs are shown in Figure 94. Additional sequential photographs are shown in Figures 95 through 98. Documentary photographs of the crash test are shown in Figures 99 and 100.

9.3 Weather Conditions

Test no. MWP-3 was conducted on July 11, 2014 at approximately 1:50 p.m. The weather conditions, as per the National Oceanic and Atmospheric Administration (station 14939/LNK), were reported and are shown in Table 14.

Table 14. Weather Conditions, Test No. MWP-3

Temperature	82° F
Humidity	67 %
Wind Speed	9 mph
Wind Direction	19° from True North
Sky Conditions	Overcast
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.14 in.
Previous 7-Day Precipitation	0.29 in.

9.4 Test Description

Initial vehicle impact was to occur 12 in. (305 mm) upstream from post no. 32, as shown in Figure 101, which was selected according to MASH. The actual point of impact was approximately 8 in. (203 mm) upstream from post no. 32. A sequential description of the impact events is contained in Table 15. The vehicle came to rest on its right side in line with the system 114 ft – 1 in. (34.8 m) downstream from the point of impact, with the system cables underneath it. The vehicle trajectory and final position are shown in Figures 94 and 102.

Table 15. Sequential Description of Impact Events, Test No. MWP-3

TIME (sec)	EVENT
0.000	Vehicle front bumper contacted cable no. 2 – 8 in. (203 mm) upstream of post no. 32.
0.002	Post no. 32 began to deflect backward and downstream as front bumper contacted post no. 32.
0.024	Post no. 33 began to deflect backward and downstream.
0.026	Vehicle left headlight contacted cable no. 4 and the left-front tire contacted post no. 32.
0.034	Vehicle left-front rim began to deform.
0.040	Vehicle left headlight contacted cable no. 3.
0.046	Vehicle left fender contacted cable no. 4 between posts no. 32 and 33.
0.050	Vehicle left-front tire became airborne and post no. 33 began to bend backward.
0.064	Vehicle hood contacted cable no. 4 and began to deform. Vehicle left-front tire overrode cable no. 1 and cable no. 4 detached from post no. 32.
0.072	Cable no. 4 detached from post no. 33.
0.080	Vehicle front bumper contacted Post no. 33. Cable no. 2 detached from post no. 33 and the vehicle began to yaw away from the barrier and roll toward the barrier. Cable no. 4 slid up over the headlight and grill and onto the vehicle hood.
0.092	Cable no. 3 detached from post no. 33 and the front bumper impacted post no. 33.
0.096	Cable nos. 4 and 3 detached from post no. 34.
0.102	Vehicle left A-pillar and left side mirror contacted Cable no. 4.
0.120	The vehicle overrode post no. 33. Cable no. 4 detached from post no. 35.
0.132	Cable no. 2 detached from post no. 35 and the left-side mirror detached from the vehicle as cable no. 4 slid upward.
0.148	Cable no. 3 detached from post no. 34.
0.166	Cable no. 3 detached from post no. 35.
0.174	Vehicle front bumper contacted post no. 34.
0.186	Cable no. 2 detached from post no. 36.

0.202	Cable no. 3 detached from Post no. 36.
0.210	Cable no. 2 detached from post no. 37. The vehicle overrode post no. 34.
0.222	Cable no. 2 detached from post no. 38.
0.238	Vehicle right rear tire became airborne. Cable no. 2 detached from post no. 39 and cable no. 4 detached from post no. 29.
0.246	Cable no. 3 detached from post no. 37.
0.274	Vehicle front bumper contacted post no. 35.
0.292	Cable no. 2 detached from post no. 40 and the left-front door began to deform. Vehicle underrode cable no. 4, which had slid up the A-pillar and was now in contact with the roof.
0.324	Vehicle right-front tire contacted post no. 35.
0.358	Cable no. 3 detached from post no. 39. Vehicle left-front tire regained contact with the ground and began rotating again.
0.378	Cable no. 3 detached from post no. 40. Vehicle left-front tire overrode cable no. 2.
0.392	Vehicle front bumper contacted post no. 36.
0.404	Vehicle was parallel to the system. Cable no. 4 was no longer in contact with the roof and was on the right side of the vehicle.
0.414	Cable no. 3 detached from post no. 41.
0.418	Vehicle right-front tire was airborne.
0.450	Cable no. 3 began to be passed down by the rotating front-left tire.
0.460	Vehicle right-side tires became airborne.
0.496	Vehicle began to yaw toward the barrier.
0.528	Vehicle left front tire overrode cable no. 3.
0.540	Cable nos. 2 and 3 were wrapped around the rear-left tire causing the vehicle to rapidly yaw and roll toward the barrier.
0.582	Vehicle was again parallel to the system.
0.800	Vehicle rear-right tire overrode cable no. 4 as the bed of the pickup swung in front of the barrier. Front-right tire overrode cables nos. 2 and 3. All cables were now under the vehicle running between the right-side tires.
1.024	Vehicle underside contacted posts no. 40 and 41.
1.122	Vehicle left-rear tire became airborne.
1.136	Vehicle right-front door contacted post no. 42 and began to deform. Vehicle left-front tire became airborne.
1.170	Vehicle right-rear and right-front tires regained contact with ground. Vehicle heading angle was approximately 45 degrees toward the barrier.
1.300	Vehicle right rear door contacted post no. 43 and began to deform.
2.014	Vehicle right rear tire contacted post no. 46 causing the vehicle to roll downstream.
2.696	Vehicle roof contacted ground before beginning to roll back onto its right side.
4.328	Vehicle came to a rest on its right side 114 ft – 1 in. (34.8 m) downstream of impact location. Barrier cables were underneath the vehicle.

9.5 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 103 through 108. Barrier damage consisted of bent posts, disengaged cables, and bent and fractured brackets. The concrete foundation at the upstream end anchor shifted downstream 0.84 in. (21 mm), as measured by the string potentiometer. The maximum splice pullout was observed on cable no. 3 located at the downstream cable end anchor with a pullout of ¼ in. (6 mm).

Cable no. 4 disengaged from post nos. 25 and 27 through 47 due to the brass rods fracturing. Cable no. 3 disengaged from post nos. 33 through 43 and post nos. 45 through 53. Cable no. 2 disengaged from post nos. 33 through 61. Cable no. 1 disengaged from post nos. 34 through 36, 38, and 39. The majority of the released brackets on cable nos. 1 and 2 opened up, with the tabs rotating through the keyhole to release the cables vertically. The brackets that released cable no. 3 were typically fractured due to high lateral loads.

Plastic deformation, in the form of bending and twisting, occurred to post nos. 32 through 48. The posts typically bent backward and downstream. In addition to the bending, post nos. 31 through 41 typically twisted to face upstream while post nos. 42 through 48 typically twisted to face downstream. The bent posts formed plastic hinges at or just below the groundline.

The maximum dynamic deflection of the system was 81 in. (2,057 mm), as determined from high-speed digital video analysis. The working width of the system was found to be 101 in. (2,565 mm), also determined from high-speed digital analysis.

9.6 Vehicle Damage

The damage to the vehicle was extensive, as shown in Figures 109 and 110. The maximum occupant compartment deformations are listed in Table 16, along with the deformation limits established in MASH for various areas of the occupant compartment. Note that the MASH-established deformation limits for the roof were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

Table 16. Maximum Occupant Compartment Deformations by Location, Test No. MWP-3

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	¼ (6)	≤ 9 (229)
Floor Pan & Transmission Tunnel	¼ (6)	≤ 12 (305)
Side Front Panel (in Front of A-Pillar)	¼ (6)	≤ 12 (305)
Side Door (Above Seat)	½ (13)	≤ 9 (229)
Side Door (Below Seat)	¼ (6)	≤ 12 (305)
Roof	>4 (102)	≤ 4 (102)

Due to the vehicle rolling, numerous dents, gouges, and scrapes were present on the right side and roof of the vehicle. The right-rear window was completely broken out, and the right-front window and windshield were both shattered. A 7-in. x 1-in. (178-mm x 25-mm) hole was found in the front windshield. Extensive crushing of the right A-pillar and roof were observed, causing the gaps to form between the right-front and right-rear doors and the roof. A large dent was present on the right quarter panel, and the sheet metal below the right-front door handle was punctured from a post during the rollover.

Gouges and scrapes from cable nos. 2 and 3 were present along the left side of the vehicle starting just above the front bumper for cable no. 3 and on the front bumper for cable no. 2. Striations from cable nos. 2 and 3 were present along the outer circumference of both left tires. Gouging along the outer rims of both left wheels were caused by cable no. 3. The left-front wheel rim also had a ½-in. (13-mm) dent. Contact marks from cable no. 4 were present along the left fender and extended onto the hood and over the length of the left A-pillar. A 4-in. x 8-in. (102-mm x 203-mm) dent was located behind the left headlight, which disengaged completely. Minor scrapes were present along the leading edge of the left lower control arm and the exhaust. Scrapes and dents were also found along the length of the driveshaft.

9.7 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 17. Note that the OIVs and ORAs were within the suggested limits provided in MASH. The maximum angular displacements are also given in Table 17. However, due the vehicle rolling, the maximum roll limit provided by MASH was violated. The calculated THIV, PHD, and ASI values are also shown in Table 17. The results of the occupant risk analysis, as determined from the accelerometer data, are also summarized in Figure 94. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix I.

Table 17. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MWP-3

Evaluation Criteria		**Transducer**		**MASH Limits**
		SLICE 1	**SLICE 2 (Primary)**	
OIV ft/s (m/s)	Longitudinal	-10.60 (-3.23)	-10.70 (-3.26)	≤ 40 (12.2)
	Lateral	11.25 (3.43)	11.88 (3.62)	≤40 (12.2)
ORA g's	Longitudinal	-6.58	-6.65	≤ 20.49
	Lateral	-5.64	-5.48	≤ 20.49
MAX. ANGULAR DISPL. deg.	Roll	156.76	149.47	≤75
	Pitch	-8.80	-10.91	≤75
	Yaw	-94.93	-96.67	not required
THIV ft/s (m/s)		15.22 (4.64)	15.49 (4.72)	not required
PHD g's		5.51	5.61	not required
ASI		0.49	0.50	not required

9.8 Load Cells and String Potentiometers

The pertinent data from the load cells and string potentiometer was extracted from the bulk signal and analyzed using the transducers' calibration factor. The maximum displacement of the upstream cable end anchor foundation was recorded as 0.84 in. (21 mm), while a summary of the maximum cable loads can be found in Table 18. The recorded data and analyzed results are detailed in Appendix J. The exact moment of impact could not be determined from the transducer data, as impact may have occurred prior to a measurable signal increase in the data. Thus, the extracted data curves should not be taken as precise time after impact, but rather a general timeline between events within the data curve itself.

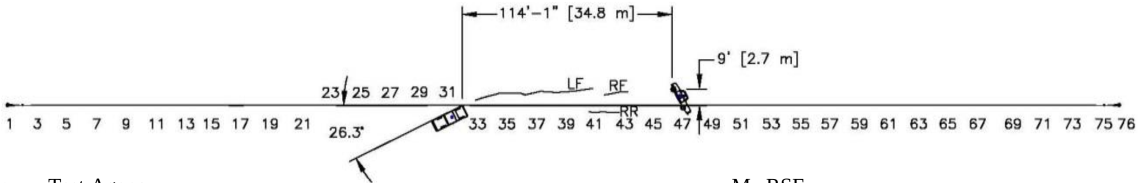
Table 18. Maximum Cable Loads, Test No. MWP-3

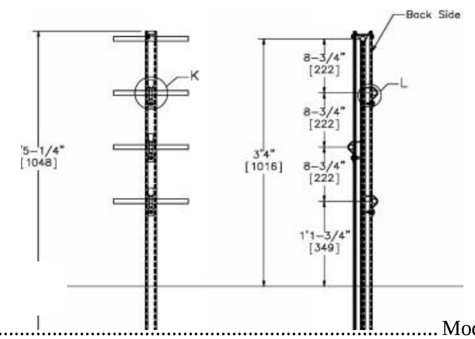
Cable Location	Sensor Location	Maximum Cable Load		Time
		kips	kN	(sec)
Combined Cable Load	Upstream of Impact	37.21	165.52	0.211
Cable No. 4	Upstream of Impact	8.42	37.45	2.064
Cable No. 3	Upstream of Impact	13.76	61.21	0.480
Cable No. 2	Upstream of Impact	14.80	65.83	0.370
Cable No. 1	Upstream of Impact	4.81	21.40	0.043

9.9 Discussion

The analysis of the test results for test no. MWP-3 showed that the high-tension four-cable median barrier did not adequately contain and redirect the 2270P vehicle. A hole was found in the windshield, qualifying as penetration of the occupant compartment. Additionally, the test vehicle penetrated the barrier system and did not remain upright during the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix I, were deemed unacceptable because the vehicle rolled over. Test no. MWP-3 conducted on the cable median barrier was determined to be unacceptable according to the MASH safety performance criteria for test designation no. 3-11.

0.000 sec 0.116 sec 0.242 sec 0.410 sec 0.744 sec





- Test Agency .... MwRSF
- Test Number.. MWP-3
- Date 7/11/2014
- MASH Test Designation 3-11
- Test Article.. Four-Cable Median Barrier
- Total Length .... 604 ft (184.1 m)
- Key Component – Bolted Tab Bracket v_10
- Key Component – Cable
  - Size .... 3x7, ¾-in. (19-mm) diameter
  - Cable Heights .... 13¾, 22½, 31¼, 40 in. (349, 572, 794, 1,016 mm)
- Key Component - MWP
  - Dimensions.. 3 x 1¾ x 83¼ in. (76 x 44 x 2,115 mm)
  - Spacing.. 8 ft (2.4 m)
- Soil Type .... Compacted, coarse, crushed limestone
- Vehicle Make /Model.. 2007 Dodge Ram
  - Curb.. 5,074 lb (2,302 kg)
  - Test Inertial.. 4,992 lb (2,264 kg)
  - Gross Static.. 5,158 lb (2,340 kg)
- Impact Conditions
  - Speed.. 60.0 mph (96.6 km/h)
  - Angle.. 26.3 deg
  - Impact Location.. 1 ft (30.5 mm) upstream of post no. 32
- Impact Severity (IS) .... 118.0 kip-ft (160.0 kJ) > 106 kip-ft (144 kJ)
- Exit Conditions
  - Speed.. NA
  - Angle .... NA
- Exit Box Criterion.. NA
- Vehicle Stability.. Unsatisfactory
- Vehicle Stopping Distance.. 114 ft 1 in. (34.8 m)
- Vehicle Damage.. Extensive
  - VDS [14] .... 11-L&T-4
  - CDC [15].. 11-LDAO-9
  - Occupant Compartment .... Penetrated and deformed
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set .... NA
  - Dynamic.. 80.7 in. (2,250 mm)
  - Working Width.. 100.7 in. (2,558 mm)
- Transducer Data

Evaluation Criteria		Transducer		MASH Limit
		SLICE 1	SLICE 2 (Primary)	
OIV ft/s (m/s)	Longitudinal	-10.60 (-3.23)	-10.70 (-3.26)	≤ 40 (12.2)
	Lateral	11.25 (3.43)	11.88 (3.62)	≤ 40 (12.2)
ORA g's	Longitudinal	-6.58	-6.65	≤ 20.49
	Lateral	-5.64	-5.48	≤ 20.49
MAX ANGULAR DISP. deg.	Roll	156.76	149.47	≤75
	Pitch	-8.80	-10.91	≤75
	Yaw	-94.93	-96.67	not required
THIV – ft/s (m/s)		15.22 (4.64)	15.49 (4.72)	not required
PHD – g's		5.51	5.61	not required
ASI		0.49	0.50	not required

Figure 94. Summary of Test Results and Sequential Photographs, Test No. MWP-3


0.000 sec


0.084 sec


0.136 sec


0.274 sec

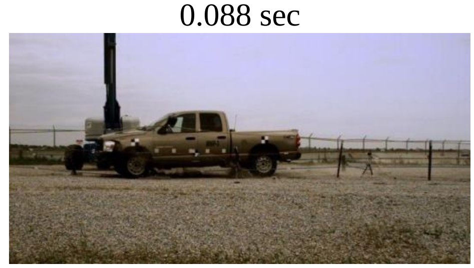

0.392 sec

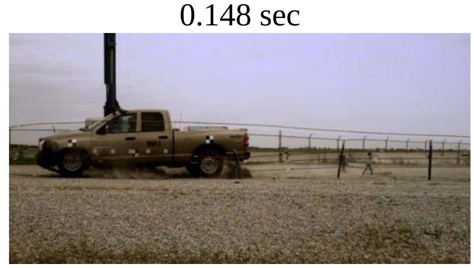

0.516 sec


0.000 sec


0.064 sec


0.088 sec


0.148 sec


0.210 sec


0.292 sec

Figure 95. Additional Sequential Photographs, Test No. MWP-3


0.000 sec


0.102 sec


0.274 sec


0.414 sec


0.538 sec


0.676 sec


0.868 sec


1.136 sec

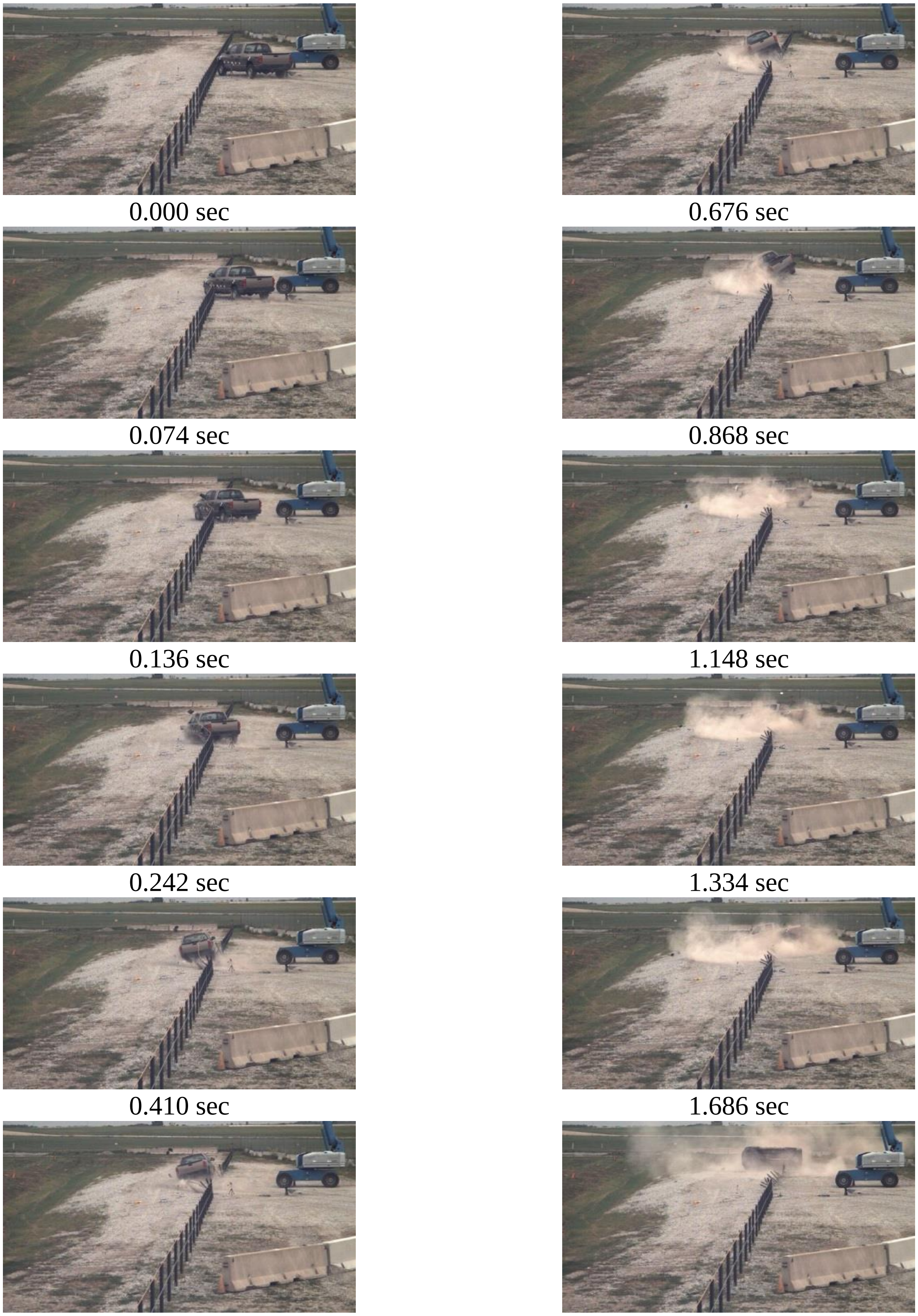

1.334 sec


2.072 sec


2.308 sec


2.726 sec

Figure 96. Additional Sequential Photographs, Test No. MWP-3



0.000 sec
0.074 sec
0.136 sec
0.242 sec
0.410 sec
0.496 sec
0.676 sec
0.868 sec
1.148 sec
1.334 sec
1.686 sec
4.328 sec

Figure 97. Additional Sequential Photographs, Test No. MWP-3

0.000 sec

0.050 sec

0.098 sec

0.134 sec

0.222 sec

0.328 sec

0.454 sec

0.744 sec

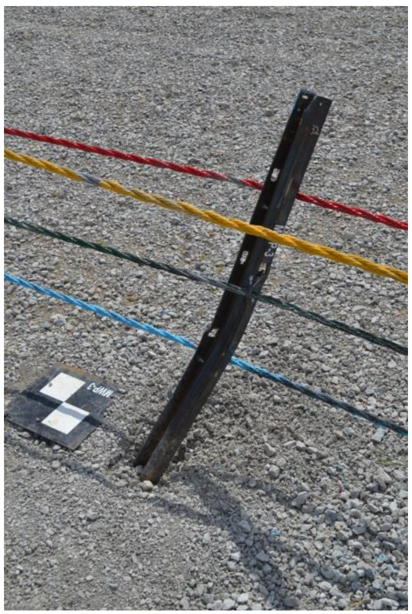
Figure 98. Additional Sequential Photographs, Test No. MWP-3

Figure 99. Documentary Photographs, Test No. MWP-3

Figure 100. Documentary Photographs, Test No. MWP-3

Figure 101. Impact Location, Test No. MWP-3

Figure 102. Vehicle Final Position and Trajectory Marks, Test No. MWP-3

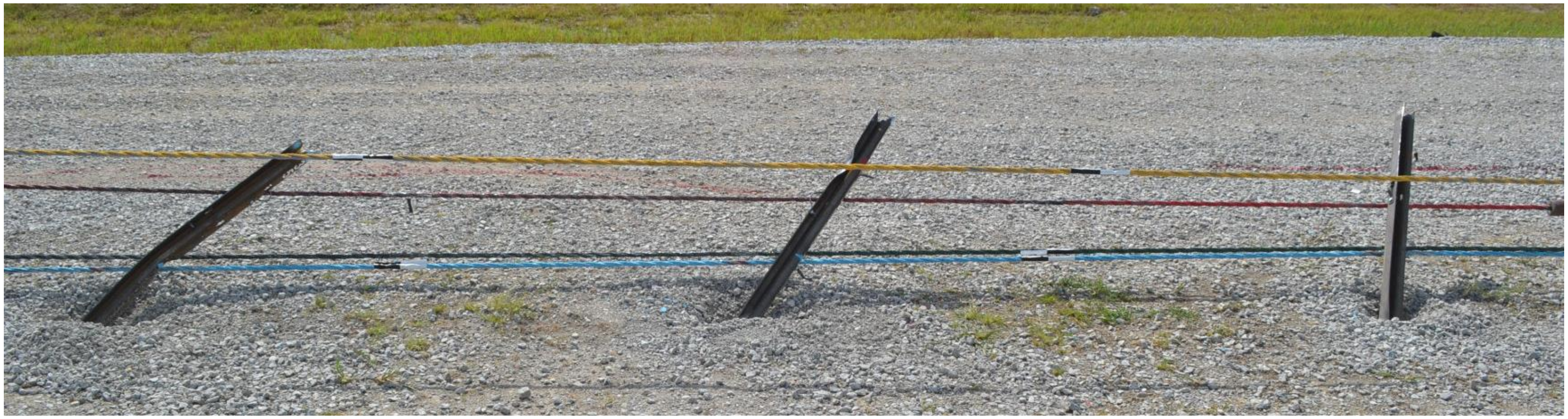


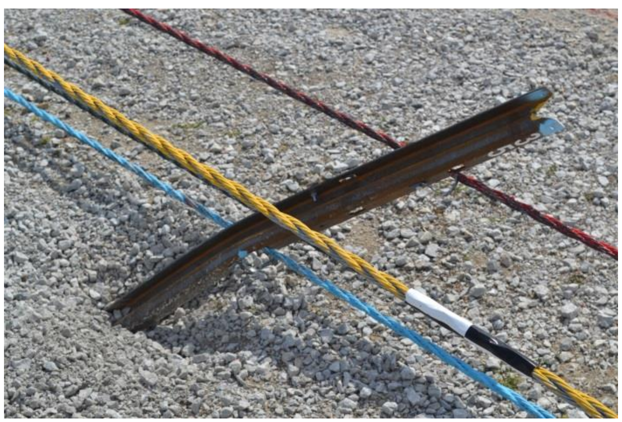
Post No. 32

Post No. 33

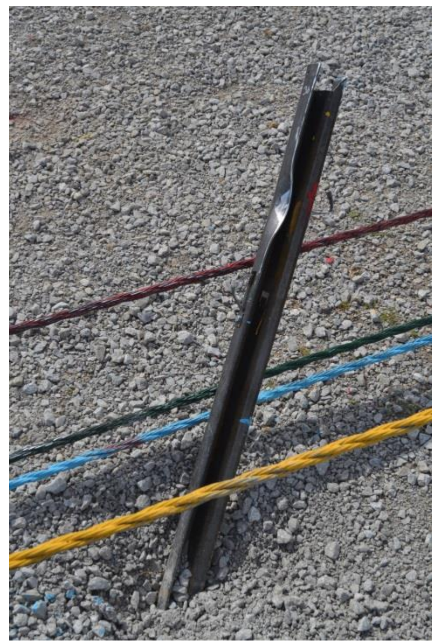
Post No. 34

Figure 103. System Damage, Post Nos. 32 through 34, Test No. MWP-3





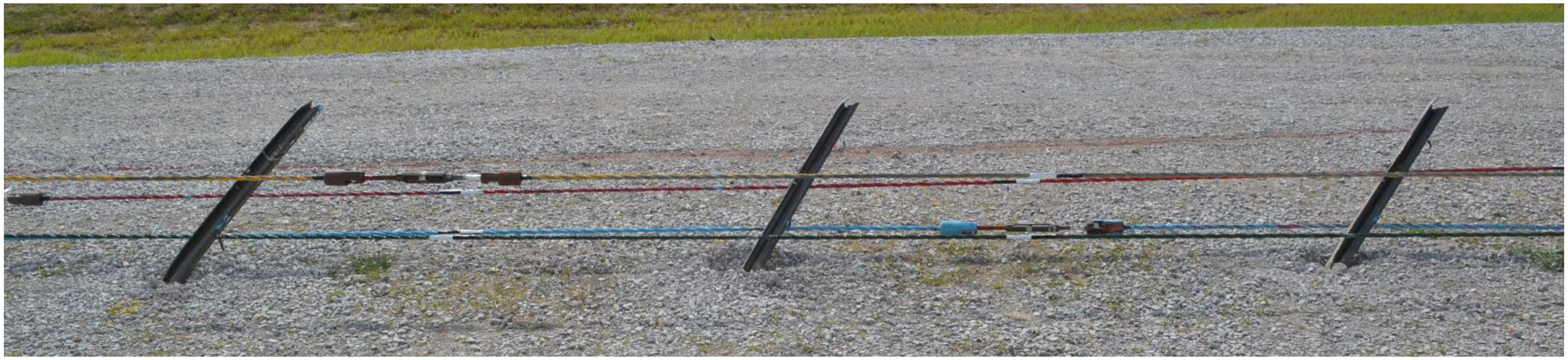
Post No. 35



Post No. 36

Post No. 37

Figure 104. System Damage, Post Nos. 35 through 37, Test No. MWP-3



Post No. 38

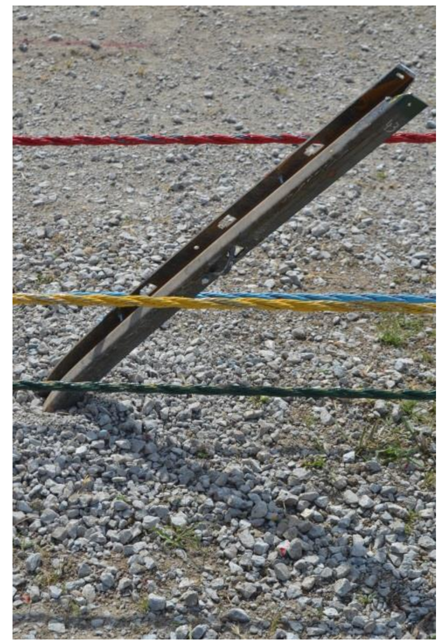
Post No. 39

Post No. 40

Figure 105. System Damage, Post Nos. 38 through 40, Test No. MWP-3

Post No. 41

Post No. 42



Post No. 43

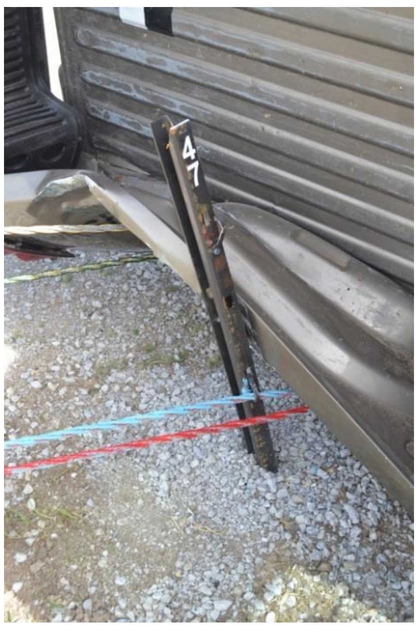
Figure 106. System Damage, Post Nos. 41 through 43, Test No. MWP-3

Post No. 44

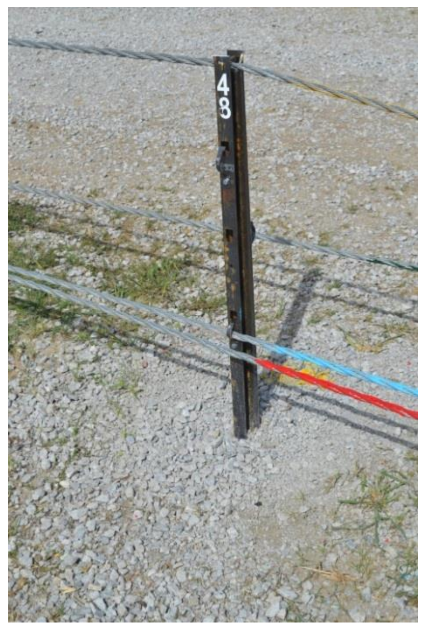
Post No. 45

Post No. 46

Figure 107. System Damage, Post Nos. 44 through 46, Test No. MWP-3



Post No. 47



Post No. 48


Post No. 49

Figure 108. System Damage, Post Nos. 47 through 49, Test No. MWP-3

Figure 109. Vehicle Damage, Test No. MWP-3

Figure 110. Vehicle Damage, Upright, Test No. MWP-3

Left-Front Wheel Assembly

Left-Rear Wheel Assembly

Figure 111. Cable Marks and Gouges on Left Side Wheel Assemblies, Test No. MWP-3

10 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The objective of this study was to evaluate a high-tension four-cable median barrier. The barrier design was developed through a series of component testing and computer simulation efforts at the MwRSF [5-7]. Through these efforts, the Midwest Weak Post (MWP) was developed to obtain the desired strong- and weak-axis bending strengths. Additionally, bolted-tabbed brackets were developed to attach the cables to the flanges of the MWPs, and a brass keeper rod was designed to hold the top cable within a V-notch cut into the top of the MWP. Although these individual barrier components performed as desired in component testing, the performance of the entire barrier system needed to be evaluated. Therefore, the high-tension four-cable median barrier was subjected to full-scale crash testing according to the proposed MASH testing matrix for cable barrier systems installed within median V-ditches.

The first full-scale crash test, test no. MWP-1, was conducted in accordance with proposed MASH test no. 3-17. The barrier was placed at the slope breakpoint of a 6H:1V slope and utilized a 16-ft (4.9-m) post spacing, representing the widest spacing recommended for the barrier system. During the test, the 1500A sedan was captured by cable no. 2 (lower middle cable) and came to rest in line with the barrier 180 ft (54.9 m) downstream from the point of impact. All occupant risk criteria were satisfied, and the A-pillar received only ¼ in. (6 mm) of deformation, as the vehicle underrode cable nos. 3 and 4. Subsequently, it was determined test no. MWP-1 had satisfied the safety performance criteria for proposed MASH test no. 3-17.

Test no. MWP-2, conducted in accordance with MASH test no. 3-11, involved a 2270P pickup truck impacting the four-cable median barrier system with 16-ft (4.9-m) post spacing on level terrain. During the test, the pickup overrode cable nos. 1 and 3, but was captured and redirected by cable nos. 2 and 4. A working width of 18 ft-5 in. (5.6 m) was observed during the test before the pickup was brought to rest 187 ft (57 m) downstream from the point of impact.

The vehicle remained stable throughout the test, and the OIV and ORA values were well below the MASH limits. Thus, test no. MWP-2 was determined to have satisfied the safety performance criteria of MASH no. 3-11.

Barrier damage resulting from test no. MWP-2 included bending of the MWPs adjacent to cable no. 1 and the tearing of the steel strip between the bottom keyway and the free edge of the post throughout a series of six posts downstream from the point of impact. To strengthen the MWPs and prevent such bending and tearing, some minor alterations were made to the posts. First, the height of the keyway was reduced by ¼ in. (6 mm). Second, the number of cable attachment points, or keyways, per post was reduced from six to four by eliminating the keyway for cable nos. 1 and 3 from one side of the post. The resulting post was no longer symmetrical, but the strength of the post cross section at these cable locations was increased. Finally, the top of the post was extended ¼ in. (6 mm) to prevent the brass keeper rod slot from collapsing during post installation/driving.

Test no. MWP-3 was also conducted in accordance with MASH test no. 3-11. However, the post spacing was reduced to 8 ft (2.4 m) to evaluate the working width of the system with the tightest recommended post spacing. During the test, the 2270P pickup was initially captured by cable nos. 2 and 3 after overriding cable no. 1 and underriding cable no. 4. However, the capture cables were eventually pushed downward and overridden by the left-front tire of the pickup. Specifically, cable nos. 2 and 3 were overridden 0.378 sec. and 0.528 sec. after impact, respectively. As a point of reference, the pickup became parallel to the system 0.404 sec. after impact. After containment of the vehicle was lost, the cables wrapped around the left-rear tire and yawed the pickup rapidly toward the barrier. The pickup ultimately rolled over as the right-side tires dug into the ground and the right side of the pickup impacted system posts. Therefore, test MWP-3 was deemed unacceptable according to MASH test no. 3-11 criteria. All three full-scale crash tests are summarized in Table 19.

As a result of the unsuccessful test, the high-tension four-cable median barrier system will need to be redesigned to prevent the loss of cable containment observed during test no. MWP-3. Possible design changes may include, but are not limited to, alternative post spacings, alternative cable heights, and the addition of a fifth cable. After the cable barrier has been redesigned, it will need to be reevaluated according to MASH test no. 3-11 criteria before being subjected to the remaining six tests listed within the recommended testing matrix for cable barriers installed within median V-ditches. Additionally, depending on the nature of the design changes, it may be necessary to retest the barrier to MASH test nos. 3-17 and 3-11 with wide post spacings.

Table 19. Summary of Safety Performance Evaluation Results, Test Nos. MWP-1 through MWP-3

<table>
<tr><th>Evaluation Factors</th><th colspan="4">Evaluation Criteria</th><th>Test No. MWP-1</th><th>Test No. MWP-2</th><th>Test No. MWP-3</th></tr>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>S</td><td>S</td><td>U</td></tr>
<tr><td rowspan="12">Occupant Risk</td><td>D.</td><td colspan="3">Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</td><td>S</td><td>S</td><td>U</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>S</td><td>S</td><td>U</td></tr>
<tr><td rowspan="5">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td><td rowspan="5">S</td><td rowspan="5">S</td><td rowspan="5">S</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s (9.1 m/s)</td><td>40 ft/s (12.2 m/s)</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td><td rowspan="4">S</td><td rowspan="4">S</td><td rowspan="4">S</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
<tr><td colspan="5">MASH Test Designation</td><td>Proposed 3-17</td><td>3-11</td><td>3-11</td></tr>
<tr><td colspan="5">Pass/Fail</td><td>Pass</td><td>Pass</td><td>Fail</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

November 3, 2015
MwRSF Report No. TRP-03-303-15

11 REFERENCES

1. Johnson, E.A., Sicking, D.L., Faller, R.K., Lechtenberg, K.A., Rohde, J.R., Bielenberg, R.W., Reid, J.D., and Rosenbaugh, S.K., *Phase I Development of a Non-Proprietary, Four-Cable, High-Tension Median Barrier,* Final Report to the Midwest States Regional Pooled Fund Program, Transportation Research Report No. TRP-03-213-11, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE, December 28, 2011.

2. Schmidt, J.D., Sicking, D.L., Faller, R.K., Lechtenberg, K.A., Bielenberg, R.W., Reid, J.D., and Rosenbaugh, S.K., *Phase II Development of a Non-Proprietary, Four-Cable, High-Tension Median Barrier,* Final Report to the Midwest States Regional Pooled Fund Program, Transportation Research Report No. TRP-03-253-12, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE, March 21, 2012.

3. Kampschneider, L.R., Homan, D. H., Lechtenberg, K.A., Faller, R.K., Bielenberg, R.W., Sicking, D.L., Reid, J.D., and Rosenbaugh, S.K., *Evaluation of a Non-Proprietary, High-Tension, 4-Cable Median Barrier on Level Terrain*, Final Report to the Midwest States Regional Pooled Fund Program, Transportation Research Report No. TRP-03-258-12, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE, November 29, 2012.

4. *Manual for Assessing Safety Hardware (MASH)*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2009.

5. Bateman, R.J., Faller, R.K., Bielenberg, R.W., Sicking, D.L., Reid, J.D., Stolle, C.S., Lechtenberg, K.A., and Rosenbaugh, S.K., *Design of Cable-to-Post Attachments for use in Non-Proprietary, High-Tension, Cable Median Barrier*, Final Report to the Midwest States Regional Pooled Fund Program, Transportation Research Report No. TRP-03-285-13, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE, August 29, 2013.

6. Mongiardini, M., Faller, R.K., Rosenbaugh, S.K., and Reid, J.D., *Test Matrices for Evaluating Cable Median Barriers Placed in V-Ditches*, Final Report to the Midwest States Regional Pooled Fund Program, Transportation Research Report No. TRP-03-265-12, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE, July 13, 2012.

7. Rosenbaugh, S.K., Bielenberg, R.W., Humphrey, B.M., Faller, R.K., Reid, J.D., and Lechtenberg, K.A, *Cable-to-Post Attachments for Use in Non-Proprietary, High-Tension, Cable Median Barrier, Phase II*, Final Report to the Midwest States Regional Pooled Fund Program, Transportation Research Report No. TRP-03-313-15, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE, June 2, 2015.

8. Bielenberg, R.W., Schmidt, T.L., Faller, R.K., Lechtenberg, K.A., Rosenbaugh, S.K., Reid, J.D., and Sicking, D.L., *Design of an Improved Post for use in a Non-Proprietary, High-Tension, Cable Median Barrier,* Final Report to the Midwest States Regional Pooled Fund Program, Transportation Research Report No. TRP-03-286-14, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE, May 7, 2015.

9. Hinch, J., Yang, T.L., and Owings, R., *Guidance Systems for Vehicle Testing*, ENSCO, Inc., Springfield, Virginia, 1986.

10. Stolle, C.S., and Sicking, D.L., *Cable Median Barrier Failure Analysis and Prevention*, Final Report to the Midwest States Regional Pooled Fund Program, Transportation Research Report No. TRP-03-275-12, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE, December 17, 2012.

11. MacInnis, D., Cliff, W., and Ising, K., *A Comparison of the Moment of Inerita Estimation Techniques for Vehicle Dynamics Simulation*, SAE Technical Paper Series – 970951, Society of Automotive Engineers, Inc., Warrendale, Pennsylvania, 1997.

12. *Center of Gravity Test Code - SAE J874 March 1981*, SAE Handbook Vol. 4, Society of Automotive Engineers, Inc., Warrendale, Pennsylvania, 1986.

13. Society of Automotive Engineers (SAE), *Instrumentation for Impact Test – Part 1 – Electronic Instrumentation*, SAE J211/1 MAR95, New York City, NY, July, 2007.

14. *Vehicle Damage Scale for Traffic Investigators*, Second Edition, Technical Bulletin No. 1, Traffic Accident Data (TAD) Project, National Safety Council, Chicago, Illinois, 1971.

15. *Collision Deformation Classification – Recommended Practice J224 March 1980*, Handbook Volume 4, Society of Automotive Engineers (SAE), Warrendale, Pennsylvania, 1985.

12 APPENDICES

Appendix A. Material Specifications

Table A-1. Table 20. Bill of Materials, Test Nos. MWP-1 and MWP-2

Item No.	Description	Material Specification	Reference
a1	Cable Anchor Base Plate	ASTM A36	N/A
a2	Exterior Cable Plate Gusset	ASTM A36	N/A
a3	Interior Cable Plate Gusset	ASTM A36	N/A
a4	Anchor Bracket Plate	ASTM A36	N/A
a5	3/16” [5] Dia. Brass Keeper Rod 14" [356] Long	Brass	Grainger COC
a6	Release Gusset	A36 Steel	N/A
a7	Release Lever Plate	A36 Steel	N/A
a8	1.25”x1.25”x0.1875” [32x32x5] TS CT Kicker Lever Tube	ASTM A500 Gr. B	N/A
a9	CMB High-Tension Anchor Plate Washer	ASTM A36	H# 64047117
a10	1.25”x1.25”x0.1875” [32x32x5] TS CT Kicker Lever Connecting Tube	ASTM A 500 Gr. B	N/A
a11	3”x10”x0.5” [76x254x13] Kicker Plate	ASTM A36	N/A
a12	CT Kicker - Gusset	ASTM A36	N/A
a13	3/4” [19] Dia. Flat Washer	ASTM F844	Grainger COC 8/03/2012
a14	3/4” [19] Dia. UNC J-Hook Anchor and Hex Nut	J-Hook ASTM A449/Nut ASTM A563 DH	BOLT: H# 11618020
a15	1/4” [6] Dia. Aircraft Retaining Cable 36" [914] Long	7x19 Galv.	N/A
a16	5/8” [16] Dia. Heavy Hex Nut	ASTM A563C	Hodel Natco Ind. COC (Lot # 49045494)
a17	5/8” [16] Dia. UNC 9 1/2" [241] Long Hex Bolt	ASTM A449 or SAE J429 Gr. 5	Hodel Natco Ind. COC (Lot # 49045494)
a18	24” [610] Dia. Concrete Anchor 120" [3048] long	4,000 psi f'c	T# 4156617
a19	#11 Straight Rebar, 114” [2896] long	Grade 60	H# 58196113
a20	#4 Anchor Hoop Rebar with 21” [533] Dia.	Grade 60	H# 111485
b1	S3x5.7 [S76x8.5] Post by 28 1/8” [714] Long	ASTM A572 GR50-07, ASTM A709 GR50-09A, ASTM A992-06A	H# 11935540
b2	S3x5.7 [S76x8.5] Post by 19” [483] Long	ASTM A572 GR50-07, ASTM A709 GR50-09A, ASTM A992-06A	H# 11935540
b3	#3 Straight Rebar, 43” [1092] Long	Grade 60	H# JW12105480
b4	7 1/4” [184] Dia. No. 3 Hoop Reinforcement	Grade 60	H# 537484
b5	2nd Post Keeper Plate, 28 Gauge	ASTM A36	N/A
b6	3/4” [19] Dia. UNC 5 1/2" [140] Long Hex Bolt and Nut	Bolt ASTM A307 Gr. A/Nut ASTM A563A	Structural Bolt Distributor's Affidavit R# 14-0343
b7	1/2" [13] Dia. Washer with 1 1/16" [27] OD	ASTM F844	Lot #: 504612-1

b8	1/2" [13] Dia. UNC 2" [51] Long Hex Bolt and Nut	Bolt ASTM A307 Gr. A/Nut ASTM A563A	Structural Bolt Distributor's Affidavit R# 14-0343
b9	4"x3"x1/4" [102x76x6] Foundation Tube 48" [1219] Long	ASTM A500 Grade B	H#B200931
b10	2nd Post Cable Hanger	ASTM A36	H# A307682
b11	2nd Post Anchor Aggregate 12" [305], Depth	-	-
b12	12" [305] Dia. 2nd Post Concrete Anchor 46" [1168] Long "	4,000 psi f'c	T# 4156617
b13	2nd Post Base Plate	ASTM A36	H# A312845
c1	3"x1-3/4"x7 Gauge [76x44x4.6] 83" [2108] Long Bent Z-Section Post	Hot-Rolled ASTM A1011 HSLA Gr. 50	H# 106387 Coil# 1118689850
c2	12-Gauge Tabbed Bracket - Version 10	Hot-Rolled ASTM A1011 HSLA Grade 50	H# 031067
c3	5/16" [8] Dia. UNC 1" [25] Long Hex Cap Screw and Nut	Bolt SAE J429 Gr. 5 or ASTM A449/Nut ASTM A563 DH	L# 1B1331706 H# 13300336-4
c4	Straight Rod - 3/16" [5] Cable Clip	ASTM B16 Brass C36000 Half Hard (HO2), ROUND. TS >=68.0 ksi, YS >= 52.0 ksi	H# 155008.1.1
d1	3/4" [19] Dia. High-Strength Pre-Stretched Cable Guiderail	3x7 Cl A Galv.	Bekaert 4060145416
d2	7/8" [22] Dia. Hex Nut	ASTM A563C	H# M643354
d3	Cable End Threaded Rod	ASTM A449	H# 133079
d4	Bennet Cable End Fitter	ASTM A47	H# 9Q4 AND OP5
x	Cable Wedges	ASTM A47	H# CG6
d5	7/8" [22] Dia. Square Nut	SAE J429 Gr. 5	N/A
e1	Bennet Short Threaded Turnbuckle	Not Specified	Ken Forging COC (9/8/1999)
e2	Threaded Loadcell Coupler	N/A	N/A
e3	50,000-lb [222.4-kN] Load Cell	N/A	N/A

Table A-2. Table 21. Bill of Materials, Test No. MWP-3

Item No.	Description	Material Specification	Reference
a1	Cable Anchor Base Plate	ASTM A36	N/A
a2	Exterior Cable Plate Gusset	ASTM A36	N/A
a3	Interior Cable Plate Gusset	ASTM A36	N/A
a4	Anchor Bracket Plate	ASTM A36	N/A
a5	3/16” [5] Dia. Brass Keeper Rod 14" [356] Long	Brass	H# 155008.1.1
a6	Release Gusset	A36 Steel	N/A
a7	Release Lever Plate	A36 Steel	N/A
a8	1.25”x1.25”x0.1875” [32x32x5] TS CT Kicker Lever Tube	ASTM A500 Gr. B	N/A
a9	CMB High-Tension Anchor Plate Washer	ASTM A36	H# 64047117
a10	1.25”x1.25”x0.1875” [32x32x5] TS CT Kicker Lever Connecting Tube	ASTM A 500 Gr. B	N/A
a11	3”x10”x0.5” [76x254x13] Kicker Plate	ASTM A36	N/A
a12	CT Kicker - Gusset	ASTM A36	N/A
a13	3/4” [19] Dia. Flat Washer	ASTM F844	PFC COC R# 14-0082
a14	3/4” [19] Dia. UNC J-Hook Anchor and Hex Nut	J-Hook ASTM A449/Nut ASTM A563 DH	BOLT: H# 11618020 NUT: Item# DHHNO75CG Lot# 170277
a15	1/4” [6] Dia. Aircraft Retaining Cable 36" [914] Long	7x19 Galv.	N/A
a16	5/8” [16] Dia. Heavy Hex Nut	ASTM A563C	Hodell Natco Ind. COC
a17	5/8” [16] Dia. UNC 9 1/2" [241] Long Hex Bolt	ASTM A449 or SAE J429 Gr. 5	Hodell Natco Ind. COC
a18	24” [610] Dia. Concrete Anchor 120" [3048] Long	4,000 psi f'c	T# 4156617
a19	#11 Straight Rebar, 114” [2896] Long	Grade 60	H# 58196113
a20	#4 Anchor Hoop Rebar with 21” [533] Dia.	Grade 60	H# 111485
b1	S3x5.7 [S76x8.5] Post by 28 1/8” [714] Long	ASTM A572 GR50-07, ASTM A709 GR50-09A, ASTM A992-06A	H# 11935540
b2	S3x5.7 [S76x8.5] Post by 19” [483] Long	ASTM A572 GR50-07, ASTM A709 GR50-09A, ASTM A992-06A	H# 11935540
b3	#3 Straight Rebar, 43” [1092] Long	Grade 60	H# JW12105480
b4	7 1/4” [184] Dia. No. 3 Hoop Reinforcement	Grade 60	H# 537484
b5	2nd Post Keeper Plate, 28 Gauge	ASTM A36	N/A
b6	3/4” [19] Dia. UNC 5 1/2" [140] Long Hex Bolt and Nut	Bolt ASTM A307 Gr. A/Nut ASTM A563A	Structural Bolt Distributor's Affidavit R# 14-0343
b7	1/2" [13] Dia. Washer with 1 1/16" [27] OD	ASTM F844	H# A32336 BL# 195624

b8	1/2” [13] Dia. UNC 2" [51] Long Hex Bolt and Nut	Bolt ASTM A307 Gr. A/Nut ASTM A563A	Structural Bolt Distributor's Affidavit R# 14-0343
b9	4”x3”x1/4” [102x76x6] Foundation Tube 48" [1219] Long	ASTM A500 Grade B	H#B200931
b10	2nd Post Cable Hanger	ASTM A36	H# A402276
b11	2nd Post Anchor Aggregate 12” [305], Depth	-	-
b12	12” Dia. 2nd Post Concrete Anchor 46" [305] Long	4,000 psi f'c	T# 4156617
b13	2nd Post Base Plate	ASTM A36	H# B314839
b14	3/16" [5] Dia. 5 1/4" [133] Long Brass Rod	ASTM B16-00	H# 155008.1.1
c1	3”x1-3/4"x7-Gauge [76x44x4.6] 83" [2108] Long Bent Z-Section Post	Hot-Rolled ASTM A1011 HSLA Gr. 50	H# 667827 Coil# 1131814950
c2	12-Gauge Tabbed Bracket - Version 10	Hot-Rolled ASTM A1011 HSLA Grade 50	H# 832D32560
c3	5/16” [8] Dia. UNC 1" [25] Long Hex Cap Screw and Nut	Bolt SAE J429 Gr. 5 or ASTM A449/Nut ASTM A563 DH	Bolts: H# 13104654-4 Nuts: H# 328711
c4	Straight Rod - 3/16” [5] Cable Clip	ASTM B16 Brass C36000 Half Hard (HO2), ROUND. TS >=68.0 ksi, YS >= 52.0 ksi	H# 155008.1.1
d1	3/4” [19] Dia. High-Strength Pre-Stretched Cable Guiderail	3x7 Cl A Galv.	Berkaert 4060145416
d2	7/8” [22] Dia. Hex Nut	ASTM A563C	H# M643354
d3	Cable End Threaded Rod	ASTM A449	H# 133079
d4	Bennet Cable End Fitter	ASTM A47	H# 9Q4 AND OP5
x	Cable Wedges	ASTM A47	H# BR1
d5	7/8” [22] Dia. Square Nut	SAE J429 Gr. 5	N/A
e1	Bennet Short Threaded Turnbuckle	Not Specified	Ken Forging COC (4/8/1999)
e2	Threaded Loadcell Coupler	N/A	N/A
e3	50,000-lb [222.4-kN] Load Cell	N/A	N/A

TC Industries Test Center
3703 South Route 31
Crystal Lake, IL 60012-1412
Telephone (815) 459-2400 Fax (815) 459-3419

TEST REPORT

REPORT NO: 168646
DATE: JULY 30, 2013
PAGE 1 OF 1

BILL TO: AMERICAN EAGLE STEEL
317 EAST 11TH STREET
CHICAGO HEIGHTS, IL 60411

SHIP TO: AMERICAN EAGLE STEEL
317 EAST 11TH STREET
CHICAGO HEIGHTS, IL 60411

DESC: 362 PCS .875"RD X 24' | HEAT: 133079 | GRADE: 1045 | WT: 17740
PO: 1563-TC | MO: 60190 | CO: 1563 | LOT: 88006

SPEC: QUENCH,TEMPER,STRAIGHTEN PINK ENDS — ASTM A449-10

PROCESS: FURN TEMP: 1600 | FURN TIME hh.mm: 1.00 | QUENCH: WATER
TEMPER TEMP: 1125 | TEMPER TIME hh.mm: 1.00
STRESS TEMP: | STRESS TIME hh.mm:

PARAMETER	UNITS	LIMITS		TEST RESULTS					
TENSILE	KSI	120.0	N/A	143.0					
YIELD .2%	KSI	92.0	N/A	130.0					
ELONG 2"	%	14.0	N/A	17.0					
RED AREA	%	35.0	N/A	48.0					
SURF HB	HBW	255	321	282	285	285	293	285	285
				285	285				

(See sampling plan on back)

4CMwP
Cable End Threaded Rod A449/1045
White Paint for Left
Red Paint for Right
Bennett Bolt Lot# 83219(left)83218(right)
Feb 2014 SMT

ACCREDITED
Testing Cert #1281-01

TC INDUSTRIES and SUBCONTRACTED LABS (A2LA ACCREDITED)

Tensile, Standard TC Tensile, Full Size Charpy V Notch Microhardness,Knoop*	Rockwell Brinell TC Ultra Sonic* Bend Test*	Micro Analysis Decarb Measure Chemistry*

TC: TC Test Center	BE: Berg Eng.	EX: Exova	MSI: Metallurgical Ser.
Cert #1281.01	Cert #L1157-1	Cert #104.02	Cert #0510.01
2/28/15	2/4/14	6/30/14	12/31/14

Time 17:39 DATE IN: 7/20/13 *not included in our scope of accreditation FC 4.12.16F 7/15/10
NOTES:

Ken Rueff

Ken Rueff
Test Center Supervisor

There are no deviations from test methods unless noted. It should not be assumed that mechanical properties of raw material heat treated to a fastener standard will have the same properties of a finished fastener whose original material characteristics may have been significantly altered.
No mercury was used/added and no welding/weld repair was performed on this material while in the possession of TC Industries, Inc.
This test report relates only to the items tested and shall not be reproduced, except in full, without the written permission of TC Industries Test Center.

Figure A-1. Cable End Threaded Rod, Test Nos. MWP-1 through MWP-3

ASI ALTON STEEL INC

CERTIFIED MILL TEST REPORT

Alton Steel Test Lab
#5 Cut Street
Alton, IL 62002-9011
(618) 463-4490 EXT 2486
(618) 463-4491 (Fax)

BILL TO

American Eagle Steel Co., Inc
317 East 11th Street
Chicago Heights, IL 60411

SHIP TO

American Eagle Steel Co., Inc
CWC - To Be Delivered To Customer's Truc
Alton, IL 62002

Date	06/10/2013	Customer PO	1563	**Specifications**
ASI Ord No.	60190	Customer PT.		
ASI Ord Line Item	1			SAE 1045

Item Description
Steel Bar, Hot Rolled, 0.8750, 24' 0 "

Strand Cast, RR =81.49:1

Heat Number	Yield PSI	Tensile PSI	% Elongation	% ROA	Bend Test

CHEMICAL ANALYSIS TEST METHODS ASTM E-415 & E-1019

Heat Number	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	Al	Nb/Cb	V	B	Ti	N	Ca
133079	0.48	0.78	0.007	0.022	0.24	0.22	0.080	0.127	0.019	0.011	0.001	0.001	0.035	0.0002	0.0008	0.0090	0.0022

JOMINY HARDENABILITY USING ASTM A-255 CALCULATED FROM CHEMICAL DI

Heat Number	GS	DI
133079	8	1.55

SPECIAL TEST RESULTS

ADDITIONAL COMMENTS

No mercury, lead, radium, of alpha containing material or equipment is used or deliberately added in the production of this steel. No weld or weld repairs were performed on this material. This Steel is 100% Electric Arc Furnace Melted and Rolled in the U.S.A. Material qualifies as NAFTA origination.

Subscribed and sworn to before me, a Notary Public, in and for the county of Madison, State of Illinois

this ____________ Day of ____________________

My commission expires____________________

____
(Notary Public)

Alteration or reproduction of this report, except in full, is not allowed without written approval by a representative of Alton Steel Incorporated.

I hereby certify that the above tests are correct as contained in the records of ALTON STEEL INCORPORATED

Quality Leader: Rubert Cauley

R Cauley

Figure A-2. Cable End Threaded Rod, Test Nos. MWP-1 through MWP-3

GRAINGER
FOR THE ONES WHO GET IT DONE

August 03 2012

W.W. Grainger, Inc.
100 Grainger Parkway
Lake Forest, IL. 60045-5201

Attn: KEN KRENK
UNIVERSITY HEALTH CENTER
1500 U STREET
LINCOLN, NE, 68503-0000

Fax #

Grainger Sales Order #: 1157994181
Customer PO #: 045562765

Dear KEN KRENK
As you requested, we are providing you with the following information. We certify that, to the best of Grainger's actual knowledge, the products described below conform to the respective manufacturer's specifications as described and approved by the manufacturer.

Item #	Description	Vendor Part #	Catalog Page #
4FGZ8	Threaded Rod,Gr 2,3/4-10 x 6 Ft,RH,UNC	4FGZ8	3060
2FE85	Hex Nut,Grade 2,3/4-10,PK20	HNG20750010020Z	2929
6PU26	Flat Washer,Ylw Zinc,Fits 3/4 In,Pk 20	HS-0750SAEHZYBAGGR	2957

If you need any additional information, please contact our Compliance Team at 847-647-4649 or prod_mgmt_support@grainger.com.

Gary Figiel

Gary Figiel
Engineering Technician
Compliance Team
Grainger Industrial Supply

Figure A-3. ¾ in. Flat Washer, Test Nos. MWP-1 and MWP-2

Low Deflection Washers R#14-0082

Porteous Fastener Company
BOLTS NUTS SCREWS WASHERS

FIRST CLASS SERVICE

CORPORATE OFFICE
1040 Watson Center Road, Carson, CA 90745
(310) 549-9180 Fax (310) 835-0415
www.porteousfastener.com

February 7, 2013

Attn: Chris

The Structural Bolt
Dear: Chris,

You contacted our Denver office and requested that I write to you concerning specifications under which we purchase our USS Flat Washers

Firstly, our products are purchased to specifications where applicable. Our Purchase Orders clearly state that each product supplied to Porteous Fastener Company is to meet the proper specification as referenced in the Industrial Fastener Institute manual for that product when such specifications exist.

(ANSI B18.22.1 and ASTM F844. All HDG plating shall be done per ASTM A153)

Secondly, we require certifications from our suppliers of all products Grade 5 or better: A325 Structural Bolts, Grade 5 Hex Cap Screws, Grade 8 Hex Cap Screws, ASTM A194 2H Hvy. Hex Nuts, F436 Structural Washers, Grade 8 Finished Hex Nuts, ASTM A193 Grade B7 Threaded Rod, SAE Hi Nuts and Grade C Hex Locknuts. These certifications are on file at Porteous corporate office and copies of same are available to our customers.

We trust that you can be confident, as we are, that the product furnished to you meets specifications.

Please let me know if we can be of further service.

Sincerely,
Herbert Recinos
Inventory Control
Cc: Mike Hall -- Denver

Figure A-4. ¾ in. Flat Washer, Test No. MWP-3

CAUTION
FRESH CONCRETE

Body and or eye contact with fresh (moist) concrete should be avoided because it contains alkali and is caustic.

Ready Mixed
Concrete Company

6200 Cornhusker Highway, P.O. Box 29288
Lincoln, Nebraska 68529
Telephone 402-434-1844

PLANT	MIX CODE	YARDS	TRUCK	DRIVER	DESTINATION	CLASS	TIME	DATE	TICKET
04	25513000	3.00	0135	056			10:23AM	03/12/14	4156617

CUSTOMER	JOB	CUSTOMER NAME	TAX CODE	PARTIAL	NIGHT R.	LOADS
00003		CIA---MIDWEST ROADSIDE SAFTEY				1

DELIVERY ADDRESS	SPECIAL INSTRUCTIONS	P.O. NUMBER
4800 NW. 35TH	N OF N GOODYEAR HANGER	402-450-6250

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION		UNIT PRICE	AMOUNT
3.00	3.00	3.00	25513000	L5500 (HE) .40	4.00	104.91	314.73
				MINIMUM HAUL			40.00
				WINTER SERVICE			12.00
							366.73

WATER ADDED ON JOB AT CUSTOMER'S REQUEST 0 GAL.   RECEIVED BY [illegible]

SUBTOTAL	366.73
TAX	
TOTAL	366.73

TRUCK	USER LOGIN	DISP TICKET NUM	TICKET NUM	TICKET ID	TIME	DATE
0135	USER	4156617	176448	191052	10:23	03/12/2014

LOAD SIZE	MIX CODE	SEQ	LOAD ID
3.00 yd	255	W	193041

MATERIAL	SOURCE	DESIGN QTY	REQUIRED	BATCHED	VAR	% VAR	%MOISTURE	ACTUAL WAT
G47B	47B GRAVEL	1915.0 lb	5825.4 lb	5800.0	-25.4	-.44%	1.40 M	9.60 gl
L47B	47B ROCK	833.0 lb	2509.0 lb	2500.0	-9.0	-.36%	0.40 M	1.19 gl
CEM1	CEMENT TYP	752.0 lb	2256.0 lb	2245.0	-11.0	-.49%		
LRWR	POZZ 322N	23.0 oz	69.0 oz	69.0	0.0	0.00%		
AIR	MB-AE 90 A	3.0 oz	9.0 oz	9.0	0.0	0.00%		
WATER	WATER	34.0 gl	94.2 gl	94.9	0.7	0.74%		94.91 gl
WATER2	RECYCLE WA	0.0 gl #	0.0 gl	0.0	0.0	0.00%		

NON-SIMULATED NUM BATCHES: 1
LOAD TOTAL: 11342 lb DESIGN W/C: 0.377 WATER/CEMENT: 0.393A DESIGN WATER: 102.0 gl ACTUAL WATER: 105.7 gl
SLUMP: 4.00 "# WATER IN TRUCK: 0.0 gl

MWP-1 Concrete Anchorage (6:1 Slope)
R# 14-0353 SMT

ORIGINAL

Figure A-5. Concrete Anchor, Test No. MWP-1

EVRAZ ROCKY MOUNTAIN STEEL
A DIVISION OF EVRAZ INC. NA

P.O. Box 316
Pueblo, CO 81002 USA

MATERIAL TEST REPORT

Date Printed: 16–DEC–10

Date Shipped: 16–DEC–10	Product: DEF 10mm	Specification: ASTM–A–615M09b GR 420/ ASTM–A–706M09l
FWIP: 52815347	Customer: CONCRETE INDUSTRIES INC	Cust. PO: 86205

CHEMICAL ANALYSIS (Heat cast 09/27/10)

Heat Number	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Al	V	B	Cb	Sn	N	Ti
537484	0.26	1.24	0.015	0.007	0.24	0.25	0.08	0.14	0.013	0.004	0.037	0.0006	0.000	0.013	0.0081	0.002

Carbon Equivalent = 0.487

MECHANICAL PROPERTIES

Heat Number	Sample No.		Yield (Psi)	Ultimate (Psi)	Elongation (%)	Reduction (%)	Bend	Wt/ft
537484	01		68260	98900	17.3		OK	0.372
		(MPa)	470.6	681.9				
537484	02		66012	96040	16.5		OK	0.372
		(MPa)	455.1	662.2				

All melting and manufacturing processes of the material subject to this test certificate occurred in the United States of America.
ERMS also certifies this material to be free from Mercury contamination.

This material has been produced and tested in accordance with the requirements of the applicable specifications. We hereby certify that the above test results represent those contained in the records of the Company.

Mark f Espamer

Quality Assurance Department

Figure A-6. Steel Rebar within Hanger Post Foundations, Test Nos. MWP-1 through MWP-3

EVRAZ ROCKY MOUNTAIN STEEL
A DIVISION OF EVRAZ INC. NA

P.O. Box 316
Pueblo, CO 81002 USA

MATERIAL TEST REPORT

Date Printed: 21–MAR–12

Date Shipped: 21–MAR–12	Product: DEF 13mm	Specification: ASTM–A–615M09b GR 420/ASTM–A–706M09b
FWIP: 52815348	Customer: CONCRETE INDUSTRIES INC	Cust. PO: 93051

CHEMICAL ANALYSIS (Heat chemistry entered 03/05/12)

Heat Number	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Al	V	B	Cb	Sn	N	Ti
111485	0.27	1.23	0.012	0.024	0.24	0.31	0.13	0.10	0.044		0.046	0.0003		0.014	0.0108	0.001

Carbon Equivalent = 0.494

MECHANICAL PROPERTIES

Heat Number	Sample No.		Yield (Psi)	Ultimate (Psi)	Elongation (%)	Reduction (%)	Bend	Wt/ft
111485	01		74160	103330	14.4		ok	0.664
		(MPa)	511.3	712.4				
111485	02		74037	102730	15.6		ok	0.663
		(MPa)	510.5	708.3				

All melting and manufacturing processes of the material subject to this test certificate occurred in the United States of America.
ERMS also certifies this material to be free from Mercury contamination.

This material has been produced and tested in accordance with the requirements of the applicable specifications. We hereby certify that the above test results represent those contained in the records of the Company.

Mark F Espanza

Quality Assurance Department

Figure A-7. Steel Rebar within Concrete Anchors, Test Nos. MWP-1 through MWP-3

Concrete Industries
6300 Cornhusker Highway
P.O. Box 29529
Lincoln, NE 68529-
Phone: (402)434-1800 FAX: (402)434-1899

JOB NUMBER: 8000MISC.
RELEASE NUMBER: PATTI-465
REQ. DELIVERY DATE:
PAGE: 1 of 1
JOB NAME: JOB COMPLETE
CC: RAM
CUSTOMER: MIDWEST ROADSIDE SAFETY FACILITY
BY: PKL

MATERIAL TYPE: Rebar, Grade 60, Black
REFERENCE:
DRAWING ID:
DESCRIPTION: 4-CABLE MEDIAN BARRIER

	Itm	Qty	Size	Length	Mark	Shape	Lbs	A	B	C	D	E	F/R	G	H	J	K	O	BC
	1	48	11	9-06			2423												0
		48.					2423.												
cl	2	135	4	7-00	401	T3	631			5-06				1-06				1-09	1
		135.					631.												
cl	3	66	3	3-01	301	T3	76			2-01				1-00				0-08	1
	4	27	3	3-07			36												0
		93.					112.												

Total Weight: 3,166 Lbs

Longest Length: 9-06

REBAR PLANT

WEIGHT SUMMARY

Rebar, Grade 60, Black

SIZE	TOTAL ITEMS	TOTAL PIECES	TOTAL LBS	STRAIGHT ITEMS	STRAIGHT PIECES	STRAIGHT LBS	LIGHT BENDING ITEMS	LIGHT BENDING PIECES	LIGHT BENDING LBS	HEAVY BENDING ITEMS	HEAVY BENDING PIECES	HEAVY BENDING LBS
3	2	93	112	1	27	36	1	66	76	0	0	0
4	1	135	631	0	0	0	1	135	631	0	0	0
11	1	48	2423	1	48	2423	0	0	0	0	0	0
	4	276	3166	2	75	2459	2	201	707	0	0	0

Total Weight: 3,166 Lbs

Longest Length: 9-06

4 Cable Anchor Cage Rebar
Pink Paint
R# 13-0074 SMT

v7.20.1846 (T) (LIN) ©2012 aSa UNAUTHORIZED REPRODUCTION PROHIBITED Thursday, August 16, 2012 9:33 AM

Figure A-8. Rebar in Concrete Anchors, Test Nos. MWP-1 through MWP-3

Ready Mixed Concrete Company
6200 Cornhusker Highway, P.O. Box 29288
Lincoln, Nebraska 68529
Telephone 402-434-1844

CAUTION
FRESH CONCRETE
Body and or eye contact with fresh (moist) concrete should be avoided because it contains alkali and is caustic.

PLANT	MIX CODE	YARDS	TRUCK	DRIVER	DESTINATION	CLASS	TIME	DATE	TICKET
01	24033000	3.00	0120		NTE		12:25PM	03/21/13	1161319

CUSTOMER	JOB	CUSTOMER NAME	TAX CODE	PARTIAL	NIGHT R.	LOADS
00003		CIA---UNLMRS				1

DELIVERY ADDRESS	SPECIAL INSTRUCTIONS	P.O. NUMBER
4800 NW 35TH	NORTH OF GOODYEAR HANGER	4506250

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION		UNIT PRICE	AMOUNT
3.00	3.00	3.00	24033000	L4000 TYPE 3	4.00	102.39	307.17
				MINIMUM HAUL			40.00
						SUBTOTAL	347.17
						TAX	347.17
						TOTAL	347.17

WATER ADDED ON JOB AT CUSTOMER'S REQUEST 2 GAL

RECEIVED BY

TRUCK	USER LOGIN	DISP TICKET NUM	TICKET NUM	TICKET ID		TIME	DATE
0120	USER	1161319	182693	33630		12:25	03/21/2013
LOAD SIZE	MIX CODE					SEQ	LOAD ID
3.00 yd	24033000					W	33698
MATERIAL	DESIGN QTY	REQUIRED	BATCHED	VAR	% VAR	%MOISTURE	ACTUAL WAT
G47B	2090 lb	6383 lb	6360	-23	-.36%	1.80 M	13.48 gl
L47B	909 lb	2732 lb	2720	-12	-.44%	0.20 M	0.65 gl
CEM3	611 lb	1833 lb	1910 >	77	4.20%		
PROT	1.20 oz	3.60 oz	4.00	0.40	11.11%		
WATER	34.0 GL	90.8 GL	90.1	-0.7	-.77%		90.11 gl
WATER2	0.0 gl #	0.0 gl	0.0	0.0	0.00%		

NON-SIMULATED NUM BATCHES: 1
LOAD TOTAL: 11742 lb DESIGN W/C: 0.464 WATER/CEMENT: 0.455A DESIGN WATER: 102.0 gl ACTUAL WATER: 104.2 gl TO ADD: 0.0 gl
SLUMP: 4.00 "# WATER IN TRUCK: 0.0 gl ADJUST WATER: 0.0 gl /load TRIM WATER: 0.0 gl /yd

MWP-2 (Level Terrain)

Concrete Anchors

SMT

ORIGINAL

Figure A-9. Concrete Anchor, Test Nos. MWP-2 and MWP-3

LINCOLN OFFICE
825 "J" Street
Lincoln, NE 68508
Phone: (402) 479-2200
Fax: (402) 479-2276

benesch
engineers · scientists · planners

COMPRESSION TEST OF CYLINDRICAL CONCRETE SPECIMENS - 6x12

ASTM Designation: C 39

Client Name: Midwest Roadside Safety Facility
Project Name: MWP-2 (Level Terrain)
Placement Location: MWP-2 (Level Terrain)

Date 01-Apr-14

Mix Designation: 4000

Required Strength: 4000

Laboratory Test Data

Laboratory Identification	Field Identification	Date Cast	Date Received	Date Tested	Days Cured in Field	Days Cured in Laboratory	Age of Test, Days	Length of Specimen, in.	Diameter of Specimen, in.	Cross-Sectional Area, sq.in.	Maximum Load, lbf	Compressive Strength, psi.	Required Strength, psi.	Type of Fracture	ASTM Practice for Capping Specimen
ZIT- 1	A	3/21/2014	3/31/2014	4/1/2014	10	1	11	12	6.02	28.46	156,750	5,510	4,000	5	C 1231

These were actually poured in 2013. SMT

Remarks:

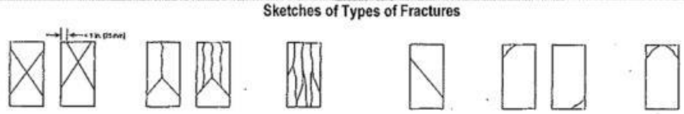
All concrete test data in this report was produced by Benesch personnel using ASTM Standard Methods and Practices unless otherwise noted.

Test results presented relate only to the concrete sampled by Benesch personnel as referenced above.

This report shall not be reproduced except in full, without the written approval of Alfred Benesch & Company.

Report Number 2147365973
Page 1

Sketches of Types of Fractures



Type 1 Reasonably well-formed cones on both ends, less than 1 in. [25 mm] of cracking through caps

Type 2 Well-formed cone on one end, vertical cracks running through caps, no well-defined cone on other end

Type 3 Columnar vertical cracking through both ends, no well-formed cones

Type 4 Diagonal fracture with no cracking through ends; tap with hammer to distinguish from Type 1

Type 5 Side fractures at top or bottom (occur commonly with unbonded caps)

Type 6 Similar to Type 5 but end of cylinder is pointed

ALFRED BENESCH & COMPANY
CONSTRUCTION MATERIALS LABORATORY

By
Brant Wells, Coordinator

Figure A-10. Concrete Anchor, Test Nos. MWP-2 and MWP-3

SOLD TO: ADELPHIA METALS I LLC
411 MAIN ST E
NEW PRAGUE, MN 56071-

NUCOR
NUCOR CORPORATION
NUCOR STEEL TEXAS

CERTIFIED MILL TEST REPORT Page: 1

SHIP TO: ADELPHIA METALS-CUST PU
N/A
JEWETT, TX 75846-

Ship from:
Nucor Steel - Texas
8812 Hwy 79 W
JEWETT, TX 75846
800-527-6445

Date: 25-Jul-2012
B.L. Number: 611543
Load Number: 217850

Material Safety Data Sheets are available at www.nucorbar.com or by contacting your inside sales representative.

NBMG-08 January 1, 2012

LOT # / HEAT #	DESCRIPTION	PHYSICAL TESTS					CHEMICAL TESTS						
		YIELD P.S.I.	TENSILE P.S.I.	ELONG % IN 8"	BEND	WT% / DEF	C / Ni	Mn / Cr	P / Mo	S / V	Si / Cb	Cu / Sn	C.E.
PO# =>	804132												
JW1210548001	Nucor Steel - Texas	77,800	111,200	12.0%			.38	.86	.012	.026	.14	.38	.56
JW12105480	10/#3 Rebar	536MPa	767MPa				.17	.18	.045	.015	.002		
	40' A615M GR 420 (Gr60)												
	ASTM A615/A615M-12 GR 60[420]												
	AASHTO M31-07												

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed above and that it satisfies those requirements.
1.) Weld repair was not performed on this material.
2.) Melted and Manufactured in the United States.
3.) Mercury, Radium, or Alpha source materials in any form have not been used in the production of this material.

QUALITY ASSURANCE: Nathan Stewart

Figure A-11. #3 Straight Rebar, Test Nos. MWP-1 through MWP-3

GERDAU

CERTIFIED MATERIAL TEST REPORT

Page 1/1

US-ML-MIDLOTHIAN
300 WARD ROAD
MIDLOTHIAN, TX 76065
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
NEBCO INC STEEL DIVISION HAVELOCK,NE 68529 USA	CONCRETE INDUSTRIES INC LINCOLN,NE 68529-0529 USA	60/420	REBAR ROUND / #11 (36MM)

LENGTH	WEIGHT	HEAT / BATCH
60'00"	33,790 LB	5819611302

SALES ORDER	SPECIFICATION / DATE or REVISION
126287/000020	ASTM A615/A615M-09B

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
95510	1327-0000015536	08/01/2012

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	Nb %	Al %
0.44	0.87	0.012	0.022	0.23	0.24	0.07	0.09	0.027	0.007	0.025	0.021	0.002

CHEMICAL COMPOSITION

CEA706 %
0.60

MECHANICAL PROPERTIES

YS KSI	YS MPa	UTS MPa	G/L Inch	G/L mm	Elong. %
73.4	506	730	8.000	200.0	12.90

MECHANICAL PROPERTIES

Bend tes
OK

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. This material, including the billets, was melted and manufactured in the USA. We certify that these data are correct and in compliance with specified requirements. CMTR complies with EN 10204 3.1.

Bhaskar — BHASKAR YALAMANCHILI, QUALITY DIRECTOR

Tom L Harrington — TOM HARRINGTON, QUALITY ASSURANCE MGR.

Figure A-12. #11 Straight Rebar, Test Nos. MWP-1 through MWP-3

AUG/23/2012/THU 02:08 PM TSA MANUFACTURING FAX No. 4028953297 P. 001/001

P.O. # 145117

PO#	30078	SO#	89068

Item: 3/4-10 X 18 1/4 J HOOK ANCHOR

Material Specification: ASTM A449

LOT#:	11618020		
Heat Number:	11618020		
Tensile Strength PSI:	131800 PSI	Yield Strength PSI:	121800 PSI
Elongation:	20	Reduction of Area:	58
Hardness:	27 HRC	Proof Load:	NA
Macro Etch:	NA	Tempering Temp.:	1340 F

Carbon (C):	0.44	Chromium (CR):	NA
Manganese (MN):	0.71	Molybdenum (MO):	NA
Phosphorus (P):	0.013	Copper (CU):	NA
Sulfur (S):	0.034	Nitrogen (N):	NA
Silicon (SI):	0.19	Nickel (NI):	NA
Cobalt (CO):	NA	Aluminum (AL):	NA
Vanadium (V):	NA	Tin (SN):	NA
Tungsten (W):	NA	Titanium (TI):	NA
Columbium/Niobium (NB/CB):	NA	Boron (B):	NA
Calcium (CA):	NA		

We hereby certify that the material was manufactured, sampled, tested and inspected per the most recent revision of the or material specification. The foregoing data was furnished to us by our supplier or resulting from a test performed in a recognized laboratory and is on file in the records of the corporation.
Name: Kayla Patterson Date:08.13.12

Figure A-13. UNC J-Hook Anchor, Test Nos. MWP-1 through MWP-3

26Apr12 9:26 TEST CERTIFICATE No: MAR 877775

INDEPENDENCE TUBE CORPORATION
6226 W. 74TH STREET
CHICAGO, IL 60638
Tel: 708-496-0380 Fax: 708-563-1950

P/O No 4500179833
Rel
S/O No MAR 212696-001
B/L No MAR 123862-004 Shp 23Apr12
Inv No Inv

Sold To: (5017)
STEEL & PIPE SUPPLY
401 NEW CENTURY PARKWAY
KANSAS CITY WHSE.
NEW CENTURY, KS 66031

Ship To: (1)
STEEL & PIPE SUPPLY
401 NEW CENTURY PKWY
NEW CENTURY, KS 66031

Tel: 913-768-4333 Fax: 913 768-6683

CERTIFICATE of ANALYSIS and TESTS Cert. No: MAR 877775
19Apr12

Part No
TUBING A500 GRADE B(C)
4" X 3" X 1/4" X 40'

		Pcs	Wgt
		20	8,408

Heat Number	Tag No	Pcs	Wgt
B200931	621072	20	8,408

YLD=69070/TEN=81790/ELG=23.9

Heat Number *** Chemical Analysis ***
B200931 C=0.2000 Mn=0.4500 P=0.0120 S=0.0020 Si=0.0300 Al=0.0330
Cu=0.1200 Cr=0.0400 Mo=0.0100 V=0.0010 Ni=0.0400

WE PROUDLY MANUFACTURE ALL OF OUR HSS IN THE USA.
INDEPENDENCE TUBE PRODUCT IS MANUFACTURED, TESTED,
AND INSPECTED IN ACCORDANCE WITH ASTM STANDARDS.
****
CURRENT STANDARDS:
................................A500/A500M-10a
................................A513-07
................................A252-98 (2002)

Page: 1 .... Last

Figure A-14. Foundation Tube, Test Nos. MWP-1 through MWP-3

ThyssenKrupp Steel USA
1 ThyssenKrupp Drive
Calvert, AL 36513

ThyssenKrupp

Mill Certificate

CUSTOMER ORIGINAL

Order - Item	Certificate Number	Delivery No	Ship Date	Page
27519-220	1118689850	80351618-10	03/06/2013	1 of 1

CustomerNo: 10780 | Cust PO: 01010892

CustomerPart No: 27509

Customer Sold to:	Customer Ship to:	Contact - Customer Service
Norfolk Iron & Metal Company 3001 North Victory Rd. NORFOLK NE 68702 USA	Norfolk Iron & Metal Company 3003 North Victory Rd. West Plt NORFOLK NE 68702 USA	Company ThyssenKrupp Steel USA PO Box 456 CALVERT AL 36513 USA

Steel Grade / Customer Specification
HR HSLAS-F GRADE 50 [340] / 0.1750 " X 60.0000 " ACCORDING TO A1011 (Light < 0.230"(6.0 mm))

Type of Product/Surface
HR Unexposed

TEST METHOD
ASTM

MATERIAL DESCRIPTION

	ORDERED	Heat No.	Coil No.	Weight Net LB	Weight Gross LB
(mm)	4.445	106387	1118689850	59,149.030	59,149.030
(in)	0.1750				

CHEMICAL COMPOSITION OF THE LADLE

Heat No.	C	Si	Mn	P	S	Al	Cr	Cu	Mo	N
106387	0.0487	0.01	0.45	0.009	0.003	0.042	0.01	0.00	0.00	0.0048
	Ni	Nb	Ti	B	V	Ca				
	0.009	0.022	0.001	0.0001	0.001	0.003				

TENSILE TEST

Heat No.	Coil No.	Test Direction	Yield Strength	Tensile Strength	% Total Elong.
106387	1118689850	L	55.2 ksi	64.8 ksi	34.6

n
0.176

ThyssenKrupp Steel USA, LLC certify that the material herein described has been manufactured, sampled, tested and inspected in accordance with the contract requirements and is fully in compliance.

Bertram Ehrhardt
Bertram Ehrhardt
Director, Quality Assurance and Development

Figure A-15. 7-Gauge, 83-in. Long Bent Z-Section Post, Test Nos. MWP-1 and MWP-2

ThyssenKrupp Steel USA
1 ThyssenKrupp Drive
Calvert, Al. 36513

ThyssenKrupp

Mill Certificate

CUSTOMER ORIGINAL

Order - Item	Certificate Number	Delivery No	Ship Date	Page
42820-70	1131814950	80554939-10	02/27/2014	1 of 1

Customer No: 10779 Cust PO: 01013159

Customer Part No: 26576

Customer Sold to:	Customer Ship to:	Contact - Customer Service
Norfolk Iron & Metal Company 3001 North Victory Rd. NORFOLK NE 68702 USA	Norfolk Iron & Metal Company 3001 North Victory Rd. NORFOLK NE 68702 USA	Company ThyssenKrupp Steel USA P.O. Box 456 CALVERT AL 36513 USA Email: CS.Calvert@Thyssenkrupp.com Ph : 1-251-289-3000

Steel Grade / Customer Specification
Hot Roll Black Coil HSLAS-F GRADE 50 [340] / 0.1750 " X 60.0000 " ACCORDING TO A1011 {Light < 0.230"(6.0 mm)}

Type of Product/Surface
Hot Roll Black Coil Semi exposed

TEST METHOD
ASTM

MATERIAL DESCRIPTION

	ORDERED	Heat No.	Coil No.	Weight Net LB	Weight Gross LB
(mm)	4.445	667827	1131814950	47,818	47,818
(in)	0.1750				

CHEMICAL COMPOSITION OF THE LADLE *

Heat No.	C	Si	Mn	P	S	Al	Cr	Cu	Mo	N
667827	0.0550	0.02	0.42	0.013	0.004	0.049	0.01	0.01	0.00	0.0058
	Ni	Nb	Ti	B	V	Ca				
	0.011	0.018	0.000	0.0001	0.001	0.0032				

TENSILE TEST

Test Direction	Yield Strength	Tensile Strength	% Total Elong.
L	60.7 ksi	67.1 ksi	33.0

ThyssenKrupp Steel USA, LLC certify that the material herein described has been manufactured, sampled, tested and inspected in accordance with the contract requirements and is fully in compliance.

Bertram Ehrhardt

Bertram Ehrhardt
Director, Quality Assurance and Development

Rev.

Figure A-16. 7-Gauge, 83-in. Long Bent Z-Section Post, Test No. MWP-3

10/05/99 15:05 ☎14409920360 KEN FORGING 002/002

KEN FORGING

KEN FORGING, INC.

OCTOBER 5, 1999

BENNETT BOLT WORKS, INC.
12 ELBRIDGE STREET
JORDAN, NY 13080

4CMwP Turnbuckles
R# 14-0325 White Paint
Bennett Bolt Lot# 21331/18305
COC Feb 2014 SMT

CERIFICATION OF CONFORMANCE

THIS LETTER IS TO ADVISE THE TURNBUCKLES NOTED BELOW ARE MANUFACTURED IN THE UNITED STATES OF AMERICA BY KEN FORGING, INC,

THESE TURNBUCKLES ARE MANUFACTURED IN COMPLIANCE WITH FEDERAL SPECIFICATION FF-T-791 1b TYPE 1

PURCHASED ORDER NO. 7158

PART NUMBER : TB109-G TB110-G

QUANTITY SHIPPED: 8PCS. 100PCS

DATE SHIPPED: 9/8/99

KEN FORGING, INC.

1049 Griggs Road • Post Office Box 277 • Jefferson, OH 44047
(440) 993-8091 • Fax: (440) 992-0360

Figure A-17. Bennet Short Threaded Turnbuckle, Test Nos. MWP-1 through MWP-3

Customer Name	Customer PO#	Shipper No	Heat Number
UNL-MwRSF	Paid by Visa	184246	155008.1.1

CERTIFIED TEST REPORT

Trip No. 178289 Bill of Lading: 127388 Packing Slip: 203143 Ship Date: 05/16/2013

Customer No. 01293

Bill To
COPPER & BRASS SALES
PO BOX 5116
SOUTHFIELD, MI 48086-5116

Ship to
COPPER & BRASS SALES
13338 ORDEN DR., BLDG H
SANTA FE SPRINGS, CA 90670

IN-PROCESS OR FINISHED PRODUCT SAMPLES, AS INDICATED BELOW, HAVE BEEN ANALYZED AND TESTED AND FOUND TO CONFORM TO THE CHEMICAL AND PHYSICAL REQUIREMENTS OF THE SPECIFICATION INDICATED WITH THE FOLLOWING RESULTS

Copper	Lead	Iron	TOE	Zinc
ASTM B16/16M-10				
60-63	2.5-3.0	0.35MAX	0.50MAX	BALANCE

CHEMICAL ANALYSIS STATEMENT OF CONFORMITY

Chase Brass maintains chemical control according to the following statistical measures which are recalculated monthly:

Copper	Lead	Iron	TOE	Zinc
Cpk: 0.69 Mean:60.70%	Cpk: 0.36 Mean:2.89% Max: 3.00%	Mean: 0.15% Max: 0.22%	Other:0.17%	Balance

Order / Traceability No	Product	Specification No	Customer PO	Quantity	Item No. / Custom Item No.
155008.1.1	C36000 ALLOY F.C. BRASS H02 HALF HARD		5400184307	1902	0187RD12-037 CURD00477

Certified Mercury Free Material
ISO9001 Certified Quality System
Certificate Number: US003903-1 (Bureau Veritas Certification)
Material is Directive 2000/53/EC Compliant
Material is Directive 2002/95/EC (RoHS) Compliant
Material is Directive 2011/65/EU (RoHS2) Compliant
This test report meets the guidelines of EN 10204 2.1

Melted and manufactured in Korea

We hereby certify that the foregoing data is a true copy of the data furnished us by the producing mill or the data resulting from tests performed in the CHASE BRASS AND COPPER COMPANY, LLC LABORATORY.

Chase

Chase Brass and Copper Company, LLC
14212 Selwyn Drive
Montpelier, Ohio 43543-0152

By Jack A Horner
Jack A. Horner
Quality Manager

From: ThyssenKrupp Materials NA
Cust. THYSSENKRUPP ONLINE METALS Del.: 2402595928
CstAr 4345 CstOr 12818
Wgt.: 37.000 LB Date 07/19/2013

John R. Zambotti

Figure A-18. Straight Rod Cable Clip, Test Nos. MWP-1 through MWP-3

4CMwP 7/8" Nuts
R# 14-0325 White Paint
Feb 2014 SMT

INSPECTION CERTIFICATE

UNYTITE,INC.
One Unytite Drive
Peru, Illinois 61354
815-224-2221 — FAX# 815-224-3434

Customer	Specification	Size	Lot No.	Date
BENNETT BOLT WORKS 12 ELBRIDGE STREET JORDAN, N.Y. 13080	ASTM A-563 GRADE DH HEAVY HEX NUT	7/8- 9 UNC	MW471	Aug. 19,'08

Mechanical properties tested in accordance to ASTM F606/F606M, ASTM A370, ASTM E18

Chemical Composition (%)

Mill Maker	Material Size	Heat No. \ Spec.	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	
GERDAU AMER	CARBON		0.20 0.55	-	MIN. 0.60	MAX. 0.040	MAX. 0.050	-	-	-	-	-
ISTEEL(NO	STEEL	M643354	0.45	0.20	0.70	0.009	0.029	0.24	0.12	0.07	0.03	-

Shape & Dimension Inspection	ANSI B18.2.2 GOOD
Thread Precision Inspection	ANSI B1.1 CLASS 2B GOOD
Appearance Inspection	GOOD

Mechanical Property Inspection

Item	Proof Load	Cone Stripping	Hardness	Hardness	Absorbed Energy	Heat Treatment
Spec.	80,850 lbf	- kN • kgf • lbf	24-38 HRC	HRB • HB	J • kgfm • ftlbf	T:MIN.800 F
Results	n: 5 Results: GOOD	n: - Results: -	27.1 27.2 27.1 27.5 27.6 27.3	Hardness Treatment After 24 Hr.X °F (°C)	at °F (°C)	Q:FORGING Q (W.Q.) T:1149 F/45M. (W.C.) Q : Quenching T : Tempering ST : Solution Treatment

Remarks:

"DH U"

Production Quantity 71,940 pcs.

OFFICIAL SEAL
JEAN MARGHERIO
NOTARY PUBLIC - STATE OF ILLINOIS
MY COMMISSION EXPIRES:10/18/09

08-26-08

Material used for the nut was melted and manufactured in the USA. The nut was manufactured in the USA to the above specification.

We hereby certify that the material described has been manufactured and inspected satisfactorily with the requirement of the above specification.

Chief of Quality Assurance Section

Figure A-19. $^{7}/_{8}$ in. Hex Nut, Test Nos. MWP-1 through MWP-3

09/27/2007 10:02 3156893999 BENNETT BOLT WORKS PAGE 03

39622

Southeastern Bolt & Screw, Inc
1037 16th Avenue West
Birmingham, AL 35204
(205) 328-4551

MATERIAL TEST REPORT

DATE: July 7, 2004

CUSTOMER: Bennett Bolt Works, Inc.

CUSTOMER P.O.: 013218

QUANITY: 57

LAB REPORT NO.: 11065

SPECIFICATION: A449 Type 1

SIZE: 7/8-9 X 48 Double End Rod

SURFACE COATING: A153 Class C

LOT NO.: L15532 (296489-01)

MARKINGS: SBS, Three Radial Lines

CHEMISTRY

C	MN	P	S	SI	V	Cb	CR	MO
.47	.75	.010	.030	.20	.013			

MATERIAL GRADE: 1045

HEAT NO.: 734281

MECHANICAL PROPERTIES

PROOF LOAD

Applied Tensile Force, lbf	39,250
Length Measurement Differential, in	-0.0005

AXIAL TENSILE

Axial Tensile Load, lbf	60,600
Failure Location	Threads

WEDGE TENSILE

10 Degree Wedge Tensile Load, lbf
Failure Location

HARDNESS MEASUREMENTS

Rockwell C Scale	28

TEST METHODS: ASTM F606

We certify that the above test results do conform to the requirements of the specifications as shown. These test results relate only to the item tested. This document may be reproduced, but only in its entirety. All material was melted and manufactured in the USA.

Jim Waddell, Quality Assurance Manager

Figure A-20. Bennett Cable End Fitter, Test Nos. MWP-1 through MWP-3

09/27/2007 10:02 3156893999 BENNETT BOLT WORKS PAGE 04
SEP-26-2007 10:13AM FROM-Buck Co. HR 717-284-4321 T-131 P.004/004 F-840

BUCK COMPANY, INC.

897 Lancaster Pike, Quarryville, PA 17566-9738
Phone (717) 284-4114 Fax (717) 284-4321
www.buckcompany.com greatcastings@buckcompany.com

MATERIAL CERTIFICATION

Date 8-30-07 Form# CERT-7A Rev C 4-21-06

CUSTOMER Bennett Bolt, Inc

ORDER NUMBER 75590

PATTERN NUMBER CGBBWTH REV. —

This is to certify that the castings listed conform to the following specifications and comply in all respects with the drawing or ordered requirements. All Quality Assurance provisions and / or Quality Assurance requirements and / or supplementary Quality Assurance provisions have been completed and accepted. SPC data is on file and available upon request.

Type Material: Malleable Iron

Specifications: ASTM-A47

Grade or Class: 32510

Heat Number: 904

MECHANICAL PROPERTIES		CHEMICAL ANALYSIS	
Tensile Str. PSI	24,562	Total Carbon	3.70
Yield Str. PSI	45,032	Silicon	2.86
Elongation	22	Manganese	.34
		Sulfur	.016
		Phosphorus	.020
		Chrome	.025
		Magnesium	.019
		Copper	.052

PHYSICAL PROPERTIES

Brinell Hardness 163

PCS SHIPPED 20

DATE SHIPPED 8-30-07

1 of 1

Quality Assurance Representative

Quality Castings
ISO 9001, 2000 CERTIFIED
Ferritic and Pearlitic Malleable Iron, Gray and Ductile Iron, Brass, Aluminum

Figure A-21. Bennet Cable End Fitter, Test Nos. MWP-1 through MWP-3

4CMwP
Bennett Bolt Lot# 81088
R# 14-0325
Feb 2014 SMT

BUCK COMPANY, INC.

897 Lancaster Pike, Quarryville, PA 17566-9738

Phone (717) 284-4114 Fax (717) 284-4321

www.buckcompany.com greatcastings@buckcompany.com

MATERIAL CERTIFICATION

Date 6/17/13

Form# CERT-7C Rev A 4/21/06

CUSTOMER: Bennett Bolt

ORDER NUMBER 6010903

PATTERN NUMBER W1 Wedge

This is to certify that the castings listed conform to the following specifications and comply in all respects with the drawing or ordered requirements. All Quality Assurance provisions and / or Quality Assurance requirements and / or supplementary Quality Assurance provisions have been completed and accepted. SPC data is on file and available upon request. Melted & Manufactured in the USA.

Type Material: Malleable Iron

Specifications: ASTM-A47

Grade or Class: 32510

Heat Number: CG6

MECHANICAL PROPERTIES		CHEMICAL ANALYSIS	
Tensile Str. PSI	53,417	Total Carbon	2.62
Yield Str. PSI	35,361	Silicon	1.42
Elongation	11	Manganese	.35
		Sulfur	.111
		Phosphorus	.015
		Chrome	.034
		Magnesium	.001
		Copper	.411

PHYSICAL PROPERTIES

Brinell Hardness 126

PCS SHIPPED 9,218

DATE SHIPPED 6/12/13

1 OF 1

Rita Lopez
Quality Assurance Representative

Quality Castings
ISO 9001: 2008 CERTIFIED
Ferritic and Pearlitic Malleable Iron, Gray and Ductile Iron, Brass, Aluminum

Figure A-22. Cable Wedges, Test Nos. MWP-1 and MWP-2

GERDAU

US-ML-WILTON
1500-2500 WEST 3RD STREET
WILTON, IA 52778
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
STATE STEEL SUPPLY CO INC 13433 CENTECH RD OMAHA,NE 68138-3492 USA	STATE STEEL SUPPLY CO INC SIOUX CITY,IA 51102-3224 USA	A36	Flat / 1/2 X 3

LENGTH	WEIGHT	HEAT / BATCH
20'00"	34,272 LB	64047117/02

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
639595/000050		1-ASTM A6/A6M-11 2-A36/A36M-08 3-A709-11 4-AASHTO M270-11

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
P31101SW251	1334-0000007548	11/05/2013

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	V %	Nb %	Al %	Pb %
0.18	0.56	0.007	0.036	0.18	0.27	0.08	0.11	0.023	0.000	0.001	0.000	0.0003

CHEMICAL COMPOSITION

Sn %
0.010

MECHANICAL PROPERTIES

Elong. %	G/L Inch	UTS PSI	UTS MPa	YS PSI	YS MPa
26.30	8.000	66800	461	43700	301
30.00	8.000	67600	466	44100	304

GEOMETRIC CHARACTERISTICS

R:R
20.52

COMMENTS / NOTES

4CMB Cable Anchor Plate Washer

P31101SW25105

64047117

The above figures are certified chemical and physical test records as contained in the permanent records of company. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

Bhaskar — BHASKAR YALAMANCHILI, QUALITY DIRECTOR

Brett Krause — BRETT KRAUSE, QUALITY ASSURANCE MGR.

Figure A-23. CMB High Tension Anchor Plate Washer, Test Nos. MWP-1 through MWP-3

SPS Coil Processing Tulsa
5275 Bird Creek Ave.
Port of Catoosa, OK 74015

SPS STEEL & PIPE SUPPLY COMPANY INC.

METALLURGICAL TEST REPORT

PAGE 1 of 1
DATE 01/20/2014
TIME 12:42:58
USER WILLIAMR

SOLD TO
12946
Wheeler Metals, Inc.
3100 W. 40th Street North
Muskogee OK 74401

SHIP TO
12946
Wheeler Metals, Inc.
3100 W. 40th Street North
Muskogee OK 74401

Order	Material No.	Description	Quantity	Weight	Customer Part	Customer PO	Ship Date
1633447-0120	701272120	3/8 72 X 120 A36 STP MIL PLT				MSK-0110-JP	01/20/2014

Chemical Analysis

Heat No. A312845 Vendor SEVERSTAL COLUMBUS DOMESTIC Mill SEVERSTAL COLUMBUS Melted and Manufactured in the USA

Batch 0002704415 10 EA 9,192 LB Produced from Coil

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum	Boron	Copper	Aluminum	Titanium	Vanadium	Columbium	Nitrogen	Tin
0.2000	0.8200	0.0100	0.0010	0.0200	0.0400	0.0700	0.0100	0.0001	0.0700	0.0290	0.0010	0.0040	0.0010	0.0072	0.0050

Mechanical/ Physical Properties

Mill Coil No. A312845-04

Tensile	Yield	Elong	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen
68804.000	44987.000	36.10	0	0.000	0	NA			
71752.000	47961.000	33.40	0	0.000	0	NA			
72022.000	49126.000	32.10	0	0.000	0	NA			
71999.000	49570.000	31.00	0	0.000	0	NA			

Slip Base

THE CHEMICAL, PHYSICAL, OR MECHANICAL TESTS REPORTED ABOVE ACCURATELY REFLECT INFORMATION AS CONTAINED IN THE RECORDS OF THE CORPORATION.

Figure A-24. Second Post Base Plate, Test Nos. MWP-1 through MWP-3

SPS Coil Processing Tulsa
5275 Bird Creek Ave.
Port of Catoosa, OK 74015

STEEL & PIPE SUPPLY COMPANY INC.

METALLURGICAL TEST REPORT

PAGE 1 of 1
DATE 08/30/2013
TIME 13:30:18
USER GIANGRER

SOLD TO
23015
PCI Manufacturing LLC
296
Sulphur Springs TX 75483

SHIP TO
23015
PCI Manufacturing LLC
906 North Hillcrest Drive
Sulphur Springs TX 75482

Order	Material No.	Description	Quantity	Weight	Customer Part	Customer PO	Ship Date
1578953-0020	701672120	1/2 72 X 120 A36 STP MIL PLT				210449	08/30/2013

Chemical Analysis

Heat No. A307682 Vendor SEVERSTAL COLUMBUS DOMESTIC Mill SEVERSTAL COLUMBUS Melted and Manufactured in the USA

Batch 0002552987 6 EA 7,351.200 LB

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum	Boron	Copper	Aluminum	Titanium	Vanadium	Columbium	Nitrogen	Tin
0.1900	0.8300	0.0140	0.0030	0.0400	0.0400	0.0600	0.0100	0.0001	0.1000	0.0300	0.0020	0.0030	0.0010	0.0066	0.0050

Mechanical/ Physical Properties

Mill Coil No. A307682-04

Tensile	Yield	Elong	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen
73416.000	49559.000	36.20	0	0.000	0	NA			
71202.000	47760.000	33.30	0	0.000	0	NA			

Cable Hanger

THE CHEMICAL, PHYSICAL, OR MECHANICAL TESTS REPORTED ABOVE ACCURATELY REFLECT INFORMATION AS CONTAINED IN THE RECORDS OF THE CORPORATION.

Figure A-25. Second Post Cable Hanger, Test Nos. MWP-1 through MWP-3

Bill To:
STEEL AND PIPE SUPPLY
P.O. BOX 1688
MANHATTAN KS
66502 US

Ship To: 6
STEEL AND PIPE SUPPLY
401 NEW CENTURY PARKWAY
GARDNER KS
66031 US

Order Date:09/23/2011
PO No:45/167008
Mill Order No:3933756
Load No:1400655
Manifest No:2095217

CERTIFIED MATERIAL TEST REPORT
GERDAU AMERISTEEL
GERDAU AMERISTEEL
Midlothian Mill
300 Ward Road
Midlothian, TX 76065
(972)775-8241

SPECIFICATIONS	SIZE	GRADE	LENGTH	PRODUCT
ASTM A6-09, A36-08, A572-07, A992-06a	S 3 X 5.7# / S 75 X 8.5	A36/A57250	40 FT / 12.192 M	STD BEAMS

HEAT NO: 11935540

CHEMICAL ANALYSIS

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	V	Al	Nb	CE
.09	.85	.010	.021	.24	.19	.07	.09	.023	.004	.002	.003	.014	.27

PHYSICAL PROPERTIES

Yield Strength KSI	Yield Strength MPa	Tensile Strength KSI	Tensile Strength MPa	Specimen Area Sq In	Specimen Area Sq cm	Elongation %	Gage Length		Bend Test Dia. Result	ROA %
60.1	414.4	73.7	508.1	0.125	0.81	23.3	8 In	200 mm		
58.6	404.0	75.0	517.1	0.139	0.90	23.9	8 In	200 mm		

Remarks

MATERIAL COMPLIES WITH ASTM A709-36,50 & 50S FOR NON-TENSION COMPONENTS.

2part Posts

All manufacturing processes of this product, including electric arc MELTING and continuous CASTING, occurred in the U.S.A.
CMTR complies with EN 10204 3.1

"I hereby certify that the contents of this report are correct and accurate. All tests and operations performed by this material manufacturer or its sub-contractors, when applicable, are in compliance with the requirements of the material specifications and applicable purchaser designated requirements."

Signed: Tom L. Harrington Date:Sep. 28, 2011 Signed: __________ Date: __________
Tom L. Harrington: Quality Assurance Manager Notary Public (if applicable)

Page: 1 of 1

Figure A-26. S3x5.7 Steel Posts, Test Nos. MWP-1 and MWP-2

No. 3007 P. 9

THIS REPORT SHALL NOT BE REPRODUCED IN WHOLE OR IN PART WITHOUT THE PRIOR WRITTEN APPROVAL OF ArcelorMittal USA Inc.

TEST REPORT

MFG. JOB. CONTRACT NO.		PURCHASE ORDER NO. P00804ER001
VENDOR: ArcelorMittal USA Inc. QUALITY DEPARTMENT 2-106 3210 WATLING STREET EAST CHICAGO, INDIANA 46312	SHIPPER'S NO. F151456	MILL ORDER NO. 4118865
	REPORT DATE 09/13,2010	INVOICE DATE 09/13,2010 / INVOICE NO. F102129
	VEHICLE IDENTIFICATION TMCD/S352	
SOLD TO: STATE STEEL SUPPLY CO PO BOX 3224 SIOUX CITY IA 51102	SHIP TO: STATE STEEL SUPPLY OF OMAHA 13433 CENTECH ROAD OMAHA NE 68139	

ArcelorMittal

PAGE 1 OF 1

Floyd E. Demmon III
Consultant, Met. Testing & Reporting

SPECIFICATION
ARCELORMITTAL / HOT ROLLED SHEET STEEL / COILS / HSLAS-F / ASTM A 1011-10 GR 50 / NON TEMPER ROLLED / CERTIFIED CHEMISTRY / MILL EDGE

TEST RESULTS

ITEM NO.	ORDER DESCRIPTION	QUANT.	WEIGHT (LBS)	HEAT NO.	COIL/LIFT IDS DSP/ARCELORMITTAL	YLD PT LBS/SQ.IN	TENSL STR LBS/SQ.IN	ELONG IN %
	.0970 IN X 60.2500 IN COIL	1	46282	031067	05648288	58,700	70,400	2 29

Sheet Steel
4CMB Tabbed Bracket
Version 10 - 12 Gauge
Jan 22, 2014 SMT

Please note that the use of customer identification codes, if present, is not a certification that product field complies to the specifications applicable to the customer identification code, but is provided for the customer's reference and tracking. Seller guarantees only that the product complies with seller's specifications and billing designations.
All tests were performed by ArcelorMittal USA Inc., unless otherwise specified, in accordance with the following: chemical analysis per ASTM E415 and E1019; mechanical properties per ASTM A370, E8, E517, E648, JIS Z2231, Z2241, Z2253, Z2254, and EN 10 002-part 1, and Rockwell hardness per ASTM E18; core loss and permeability per ASTM A343; coating weight per ASTM A90, A428, and A754; and adherence per Powder Test Method for sheet steel. All tests performed to the current standard date, unless otherwise noted. Uncertainties of measurements were estimated, and are available when requested.

HEAT ANALYSIS (wt. %)

HEAT NO.	C	Mn	P	S	Si	Cu	Ni	Mo	Cr	Cb	V	Al	SN
031067	.05	.98	.013	.006	.03	.02	<.02	<.02	.03	.026	<.008	.041	<.02
	TI	N	B										
	.015	.0049	.0002										

"100% SMELT/MELT AND MANUFACTURED IN THE U.S.A."

Sep. 13. 2010 4:00PM

Figure A-27. 12 Gauge Tabbed Bracket, Version 10, Test Nos. MWP-1 and MWP-2

Quality Assurance Department

REPORT OF TEST AND ANALYSES

1

VENDOR	SOLD TO	SHIP TO
ARCELORMITTAL BURNS HARBOR LLC 250 WEST US HIGHWAY 12 BURNS HARBOR, IN 46304-9745	STATE STEEL SUPPLY CO PO BOX 3224 208 COURT ST SIOUX CITY IA 51102	STATE STEEL SUPPLY CO 208 COURT ST SIOUX CITY IA 51102

SHIPMENT NO.	DATE SHIPPED	MILL ORDER NO.	CAR OR VEHICLE NO.	PURCHASE ORDER NO.
86B-47178	11/12/13	ISG-YH 874-52010-A	TRLR 013	P30913BN017

MATERIAL DESCRIPTION

GAUGE	WIDTH	LENGTH	CUSTOMER APPLICATION:	SPECIFICATION:
.0970 M IN	48 IN	COIL IN	PAINTED PARTS	HOT ROLL PICKLE OUTSIDE PI & OIL & TEMPER ROLL HSLAS OIL/MEDIUM /MILL EDGE---ASTM A1011 LATEST REVIS SLAS-F GR 50 MOD 203 (SI=.050X)

ITEM — TEST RESULTS

COIL NUMBER	NO. PCS.	WEIGHT	HEAT NUMBER	TEST LOC.	YLD PT LONG.	TENSILE KSI-L	ELONG-L IN--PCT
271370 7499613	1	46240	832D32560	L F	60.1	68.3	2 29

12gauge 50ksi ASTM A1011

Midwest Posts Clips and Clip Testing

May 2014 SMT

D -> 7122773306

CHEMICAL ANALYSIS MELTED AND MANUFACTURED IN THE U.S.A.

HEAT NUMBER	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Ti	Al	Cb	N	B	SN
832D32560	.06	.42	.015	.008	.015	.029	.02	.04	.015	.001	.002	.035	.019	.005	.0002	.004
	CO	PB	AS	ZR	W	MG	CA									
	.003						.0002									

I certify that the above results are a true and correct copy of records prepared and maintained by ArcelorMittal Burns Harbor in compliance with the requirements of the specification cited above.

Not to be reproduced except for in full. Crosshead Speed Control Method Used for all Tensile Tests

Test certificates are prepared in accordance with procedures outlined in DIN EN 10204:2005 Type 3.1

DIVISION MANAGER
QUALITY ASSURANCE

D.J. FARRELL

BHTSTRPT.TIF

Page 2 of 2

Figure A-28. 12-Gauge Tabbed Bracket, Version 10, Test No. MWP-3

BEKAERT CORPORATION Van Buren,Arkansas

1881 BEKAERT DRIVE
VAN BUREN, AR 72956
,(479)474-5211 FAX(479)474-9075
LEX 537439

DATE: 06/03/2010

Customer Midwest Roadside Safety Facili
Customer Order No sample
Our Order No 4060145416 0010
Qty 3 Carriers
Product 3/4" 3X7 CL A GALV GUIDERAIL SHORTS
Customer Part No
MFG SMP No AST3043SE10S
Customer Spec No ASTM A 741

ıished ȷ#	Diameter in	Lay Length (in.)	Breaking Load lbf	Adherence Appearance of Wires	Steel Ductility
509409	0.79	6	46525	Pass	Pass
609459	0.75	7	46548	Pass	Pass
509513	0.75	7.3	49219	Pass	Pass

terial was melted and made in the U.S.A.
e undersigned certifies that the results are actual results and conform to the specification indicated
contained in the records of this Corporation.

---ss Control Manager

Notary Public Commission Expires

Figure A-29. High-Strength Pre-Stretched Cable Guiderail, Test Nos. MWP-1 and MWP-2

CERTIFICATE OF CONFORMANCE

TO: Structrual Bolt Co.,LLC

PO #: 15306
DATE OF SHIPMENT: 2/14/2014
ITEM #: IHMB0630950CZ
ITEM DESCRIPTION: 5/8-11 X 9-1/2 GR 5 Hex bolt zinc import

QUANTITY: 4
LOT #: 49045494
COUNTRY OF ORIGIN: CANADA

The above described material was produced in accordance with the applicable standards and/or applicable specifications as designated on purchase order and/or drawing that are current for these parts on the date on which the inquiry and/or order was placed.

William H. Rex
William H. Rex
Operations Manager

Hodell-Natco Industries, Inc.
7825 Hub Parkway, Valley View, Ohio 44125
(216) 447-0165 • (800) 321-4862

Figure A-30. $^{5}/_{8}$-in. Dia. UNC 9 ½-in. Long Hex Bolt, Test Nos. MWP-1 through MWP-3

PFC
FIRST CLASS SERVICE

Porteous Fastener Company
BOLTS NUTS SCREWS WASHERS

CORPORATE OFFICE
1040 Watson Center Road, Carson, CA 90745
(310) 549-9180 Fax (310) 835-0415
www.porteousfastener.com

May 30, 2013

Attn: Chris Burris

Structural Bolt
2140 Cornhusker Hwy
Lincoln NE 68521
Fax: 402-435-3135

Dear: Chris,

You contacted our Denver office concerning specifications under which we purchase our N.C. Gr. 5 Finished. Hex Nuts.

Firstly, our products are purchased to specification where applicable. Our Purchase Orders clearly state that each product supplied to Porteous Fastener Company is to meet the proper specification as referenced in the Industrial Fastener Institute manual for that product when such specifications exist.

(ASME / ANSI B18.2.2 And SAE J995, GRADE 5.)

Secondly, we require certifications from our suppliers of all products Grade 5 or better: A325 Structural Bolts, Grade 5 Hex Cap Screws, Grade 8 Hex Cap Screws, ASTM A194 2H Hvy, Hex Nuts, F436 Structural Washers, Grade 8 Finished Hex Nuts, ASTM A193 Grade B7 Threaded Rod, SAE Hi Nuts and Grade C Hex Locknuts. These certifications are on file at Porteous corporate office and copies of same are available to our customers.

We trust that you can be confident, as we are, that the product furnished to you meets specifications.

Please let me know if we can be of further service.

Sincerely,

Herbert Recinos
Inventory Control

Cc: Carrie- Denver

Figure A-31. $^{5}/_{8}$-in. Dia. Heavy Hex Nut and $^{5}/_{16}$-in. Dia. Nut, Test Nos. MWP-1 through MWP-3

THE STRUCTURAL BOLT COMPANY

DISTRIBUTOR'S AFFIDAVIT

DISTRIBUTOR:
THE STRUCTURAL BOLT CO
2140 CORNHUSKER HWY
LINCOLN, NE 68521

REFERENCE PO# 4CMB

The Strcutrual Bolt Co, hereby certifies that the items below meets or exceeds requirements per your purchase order

Quantity	Size	Descripition	Spec	Finish
20	3/4 x 5-1/2	HEX BOLT	A307	PL
20	3/4-10 NUT	HEX NUT	A307	PL
100	1/2 WASHER	FLAT WASHER	A307	PL
50	1/2-13 X 2	HEX BOLT	A307	PL
50	1/2-13 NUT	HEX NUT	A307	PL

Order# 4CMB
TSBC Inv# 108423

Distributor's Signature *Chris Burris* Date: 2/18/2014
Title: General Manager

Figure A-32. ½-in. Dia. UNC 2-in. Long Hex Bolt and Nut and ¾-in. Dia. UNC 5½-in. Long Hex Bolt and Nut, Test Nos. MWP-1 through MWP-3

ISO/TS 16949 BUREAU VERITAS Certification

GEM-YEAR TESTING LABORATORY
CERTIFICATE OF INSPECTION

MANUFACTURER GEM-YEAR INDUSTRIAL CO., LTD.
ADDRESS : NO.8 GEM-YEAR ROAD,E.D.Z.,JIASHAN,ZHEJIANG,P.R.CHINA

Tel: (0573)84185001 (48Lines)
Fax: (0573)84184488 84184567
DATE : 2013/08/26

PURCHASER : PORTEOUS FASTENER COMPANY.
PO. NUMBER : 13020511C3
COMMODITY : HEX CAP SCREW GR-5
SIZE : 5/16-18X1 NC
LOT NO : 1B1331706
SHIP QUANTITY : 79,200 PCS
HEADMARKS : CYI & 3 RADIAL LINES
COUNTRY OF ORIGINAL : CHINA

PACKING NO : GEM130723036
INVOICE NO : GEM/PFC-130821AT3
PART NO : 00050-2516-021
SAMPLING PLAN : ASME B18.18/ASTM F1470
HEAT NO : 13300336-4
MATERIAL : X35ACR
FINISH : H.T. TRIVALENT ZINC

PERCENTAGE COMPOSITION OF CHEMISTRY :

Chemistry	Al%	C%	Cr%	Mn%	P%	S%	Si%
Spec. : MIN.	0.0200	0.3500	0.2000	0.7000			
MAX.		0.3800	0.4000	0.9000	0.0250	0.0150	0.1000
Test Value	0.0260	0.3600	0.2780	0.7900	0.0140	0.0020	0.0600

DIMENSIONAL INSPECTIONS :ACCORDING TO ASME/ANSI B18.2.1
TEST DATE : 2013/08/02 SAMPLED BY : YAN WANG SAMPLING DATE : 2013/08/02

INSPECTIONS ITEM	SAMPLE	TEST METHOD	REF	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
MAJOR DIAMETER	9 PCS	MIL-STD-120		7.690-7.900 MM	7.810-7.880 MM	9	0
WIDTH ACROSS CORNERS	9 PCS	MIL-STD-120		14.150-14.650 MM	14.360-14.390 MM	9	0
HEIGHT	9 PCS	MIL-STD-120		4.960-5.350 MM	5.030-5.040 MM	9	0
NOMINAL LENGTH	26 PCS	MIL-STD-120		24.640-25.400 MM	25.100-25.140 MM	26	0
WIDTH ACROSS FLATS	9 PCS	MIL-STD-120		12.430-12.700 MM	12.570-12.700 MM	9	0
SURFACE DISCONTINUITIES	50 PCS	ASTM F788/F788M			PASSED	50	0
THREAD	9 PCS	MIL-STD-120		3A	PASSED	9	0

MECHANICAL PROPERTIES : ACCORDING TO SAE J 429-2011
TEST DATE : 2013/03/22 SAMPLED BY : LI JUN SAMPLING DATE : 2013/03/22

INSPECTIONS ITEM	SAMPLE	TEST METHOD	REF	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
CORE HARDNESS	15 PCS	ASTM F606/F606M		25-34 HRC	28-31 HRC	15	0
SURFACE HARDNESS	15 PCS	ASTM E18		Max. 54 HR30N	45-48 HR30N	15	0
TENSILE STRENGTH	5 PCS	ASTM F606/F606M		Min. 120 KSI	132-140 KSI	5	0

ALL TESTS ARE IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM/SAE/ASME/MIL-STD-120 SPECIFICATION. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.

WE CERTIFY THE PARTS ARE ROHS COMPLIANT.
THIS CERTIFIED MATERIAL TEST REPORT APPLIES TO THE SAMPLES TESTED AND IT CANNOT BE REPRODUCED EXCEPT IN FULL.

SIGNATURE : Jerry

page 1 of 1

Figure A-33. $^{5}/_{16}$-in. Dia. UNC 1-in. Long Hex Cap Screw, Test Nos. MWP-1 through MWP-3

SUPERIOR WASHER AND GASKET CORP. 170 Adams Avenue Hauppauge, New York 11788 Phone: (631) 273-8282 Fax: (631) 273-8088 E-Mail: swg@superiorwasher.com Web: superiorwasher.com **(In the East)**	SUPERIOR WASHER AND GASKET CORP. 662 Bryant Blvd. Rock Hill, South Carolina 29732 Phone: (803) 366-3250 Fax: (803) 366-3511 E-Mail: swg@superiorwasher.com Web: superiorwasher.com **(In the South)**

ACCURATE MANUFACTURE GROUP
P.O. BOX 7232 - DEPT. 168

INDIANAPOLIS , IN 46206

Customer Purchase Order Number		Superior Order Number	Superior Lot Number	Tracer No.
9454		504612-1	504612 - 1	SC31483 -3 /21153114
Date	Production Card	Part Number		Quantity
04-02-13	175383	WASB12NZ		15,000
Drawing		Dual Cert No.		
P/N S-1/2TYBNZ A				

We hereby certify that all materials and processes conform
to the required drawing specifications and that the parts
have been manufactured in the U.S.A.
All parts are manufactured in a Mercury-free environment

Material

1008 LOW CARBON STEEL No. 5

ZINC TRIVALENT CHROMIUM

Chemical Analysis

C	CARBON	.0700
Mn	MANGANESE	.3300
P	PHOSPHORUS	.0080
S	SULPHUR	.0070
Si	SILICON	.0100
Cr	CHROMIUM	.0200
Ni	NICKEL	.0100
Mo	MOLYBDENUM	.0100
Cu	COPPER	.0200
Fe	IRON	
Ti	TITANIUM	
Co	COBALT	
N	NITROGEN	
Cb	COLUMBIUM	
Al	ALUMINUM	.0430
Sn	TIN	
Mg	MAGNESIUM	
Zn	ZINC	
Pb	LEAD	
Va	VANADIUM	

Mechanical Properties

Yield	
Tensile	
Elongation	
Hardness	B 49.0
Heat	4179170
Magnetic Permeability	
Bend Test	

SUPERIOR WASHER & GASKET CORP.

By Richard Anderson Jr.
Richard Anderson, Jr.
Quality Control Manager

Figure A-34. ½-in. Dia. Washer with $1^{1}/_{16}$-in. OD, Test Nos. MWP-1 and MWP-2

Appendix B. Vehicle Center of Gravity Determination

Test: MWP-1 Vehicle: taurus

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)
+	Unbalasted Car (curb)	3205
+	Brake receivers/wires	6
+	Brake Frame	7
+	Brake Cylinder	22
+	Strobe Battery	6
+	Hub	20
+	CG Plate (EDRs)	14
+	DTS	20
-	Battery	-31
-	Oil	-5
-	Interior	-53
-	Fuel	0
-	Coolant	-16
-	Washer fluid	-3
BALLAST	Water	110
	Misc.	
	Misc.	

Estimated Total Weight 3302 lb

wheel base 108.5 in.

MASH targets		Test Inertial	Difference
Test Inertial Wt (lb)	3300 (+/-)220	3302	2.0
Long CG (in.)	N/A	40.27	NA
Lateral CG (in.)	N/A	0.334976	NA

Note: Long. CG is measured from front axle of test vehicle
Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side

CURB WEIGHT (lb)

	Left	Right
Front	1054	1061
Rear	550	540

FRONT 2115 lb
REAR 1090 lb
TOTAL 3205 lb

Dummy = 164lbs

TEST INERTIAL WEIGHT (lb)
(from scales)

	Left	Right
Front	1018	1056
Rear	613	611

FRONT 2074 lb
REAR 1224 lb
TOTAL 3298 lb

Figure B-1. Vehicle Mass Distribution, Test No. MWP-1

Test: MWP-2 Vehicle: Ram 1500

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)	Vert CG (in.)	Vert M (lb-in.)
+	Unbalasted Truck (Curb)	5058	28.60061	144661.9
+	Brake receivers/wires	6	52.5	315
+	Brake Frame	9	30	270
+	Brake Cylinder (Nitrogen)	22	28	616
+	Strobe/Brake Battery	5	32	160
+	Hub	30	15.9375	478.125
+	CG Plate (Data)	8	31.5	252
-	Battery	-43	42.5	-1827.5
-	Oil	-7	18	-126
-	Interior	-79	23	-1817
-	Fuel	-154	21	-3234
-	Coolant	-15	32	-480
-	Washer fluid	0	39	0
BALLAST	Water	166	21	3486
	DTS plate	1	27	27
	Misc.			0
				142781.5

Estimated Total Weight (lb)	5007
Vertical CG Location (in.)	28.51638

wheel base (in.) 140.5

MASH Targets	Targets	Test Inertial	Difference
Test Inertial Weight (lb)	5000 ± 110	5023	23.0
Long CG (in.)	63 ± 4	61.37	-1.63090
Lat CG (in.)	NA	-0.18041	NA
Vert CG (in.) ≥	28	28.52	0.51638

Note: Long. CG is measured from front axle of test vehicle
Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side

CURB WEIGHT (lb)

	Left	Right
Front	1494	1377
Rear	1079	1108

FRONT	2871 lb
REAR	2187 lb
TOTAL	5058 lb

TEST INERTIAL WEIGHT (lb)
(from scales)

	Left	Right
Front	1452	1377
Rear	1073	1121

FRONT	2829 lb
REAR	2194 lb
TOTAL	5023 lb

Figure B-2. Vehicle Mass Distribution, Test No. MWP-2

Test: MWP-3 Vehicle: 2270P

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)	Vert CG (in.)	Vert M (lb-in.)
+	Unbalasted Truck (Curb)	5074	28.30007	143594.6
+	Brake receivers/wires	6	50	300
+	Brake Frame	9	29	261
+	Brake Cylinder (Nitrogen)	28	26	728
+	Strobe/Brake Battery	6	31	186
+	Hub	27	15.125	408.375
+	CG Plate	17	32	544
-	Battery	-51	40	-2040
-	Oil	-4	17	-68
-	Interior	-59	22.5	-1327.5
-	Fuel	-160	19	-3040
-	Coolant	-13	37	-481
-	Washer fluid	0		0
BALLAST	Water	120	17	2040
	Misc.			0
	Misc.			0
				141105.4

Estimated Total Weight (lb)	5000
Vertical CG Location (in.)	28.22109

wheel base (in.) 140.5

MASH Targets	Targets	Test Inertial	Difference
Test Inertial Weight (lb)	5000 ± 110	4992	-8.0
Long CG (in.)	63 ± 4	62.54	-0.46174
Lat CG (in.)	NA	-0.21815	NA
Vert CG (in.) ≥	28	28.22	0.22109

Note: Long. CG is measured from front axle of test vehicle
Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side

CURB WEIGHT (lb)

	Left	Right
Front	1433	1399
Rear	1152	1090

FRONT	2832 lb
REAR	2242 lb
TOTAL	5074 lb

TEST INERTIAL WEIGHT (lb)
(from scales)

	Left	Right
Front	1394	1376
Rear	1118	1104

FRONT	2770 lb
REAR	2222 lb
TOTAL	4992 lb

Figure B-3. Vehicle Mass Distribution, Test No. MWP-3

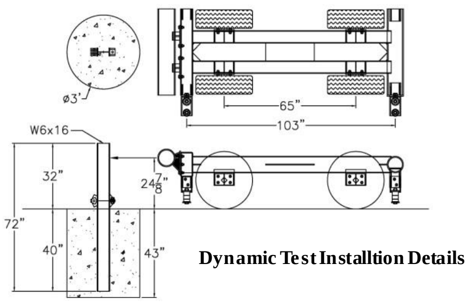
Appendix C. Static Soil Tests

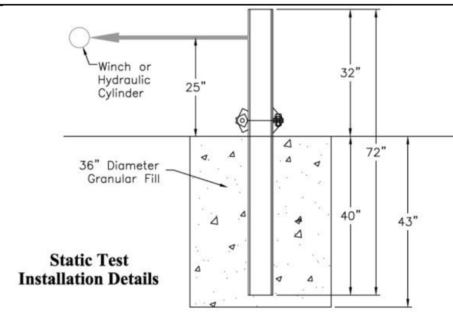
Dynamic Set up

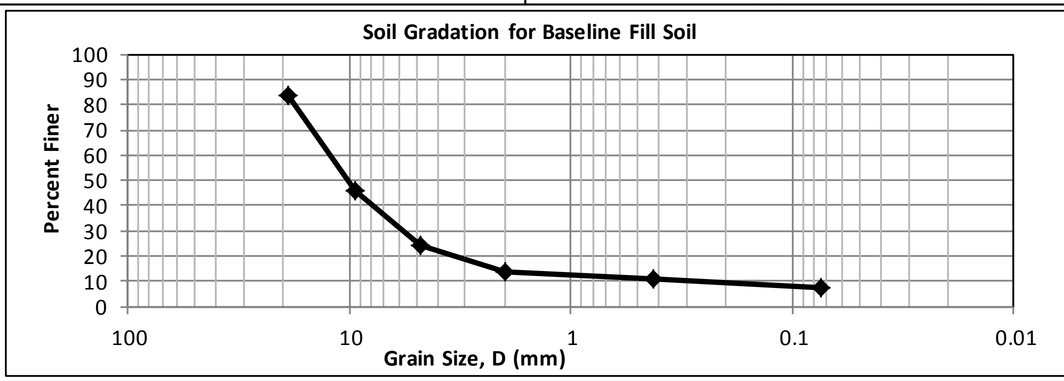
Post-Test Photo of Post

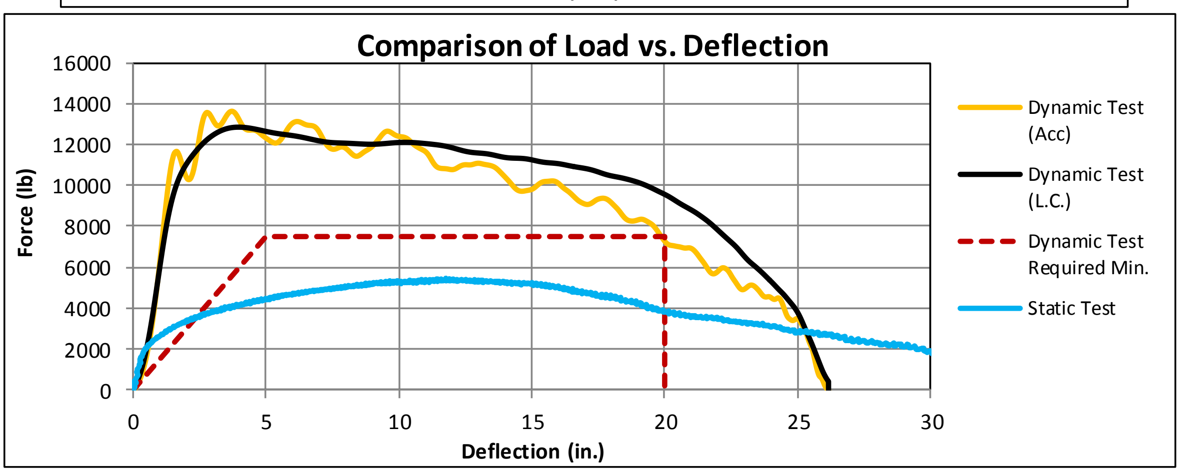
Static Load Test

Post-Test Photo of Post





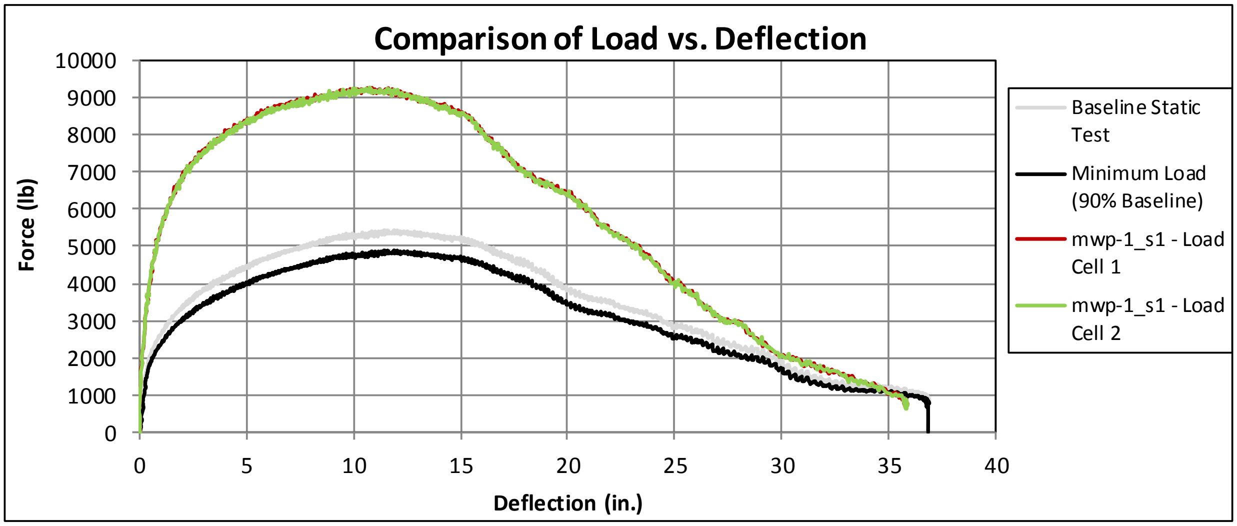


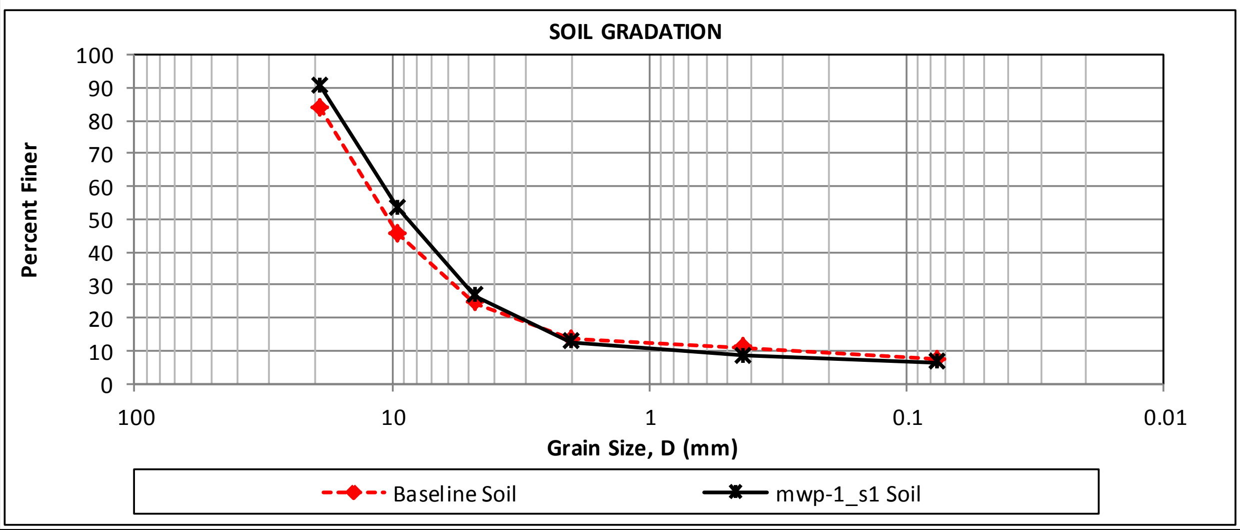


Date	3/28/2011
Test Facility & Site Location	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)	Well Graded Gravel (GW)
Fill material description (ASTM D2487)	Well Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure	8-in. Lifts, High Compaction, Pnuematic Tamper
Bogie Weight	1,727 lb
Impact Velocity	18.81 mph

Figure C-1. Soil Strength, Initial Calibration Tests, Test Nos. MWP-1 through MWP-3

Static Load Test Setup	Post-Test Photo of Post
	

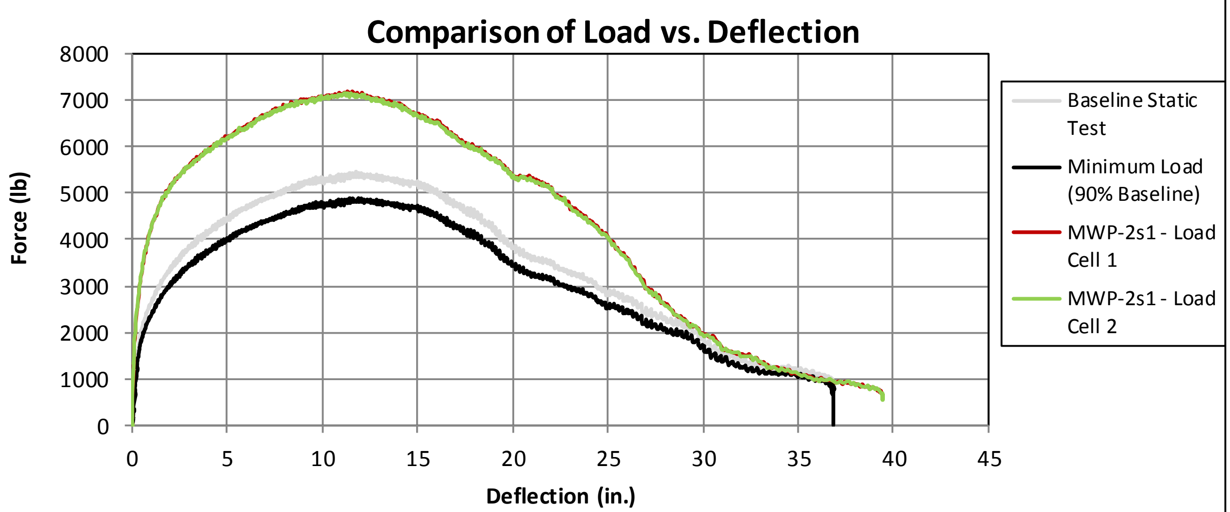


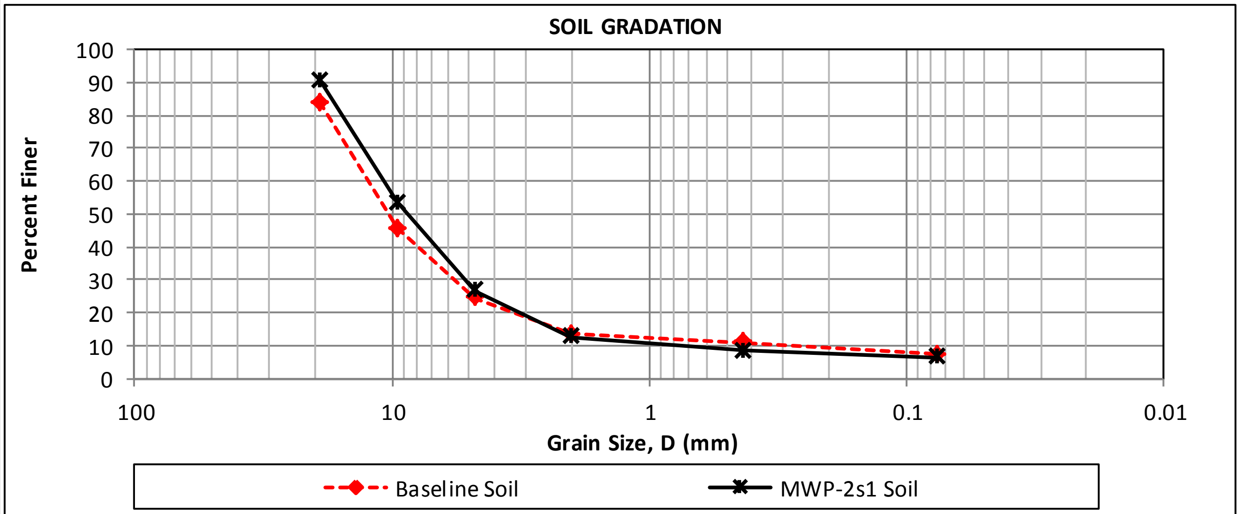


Date..	3/25/2014
Test Facility & Site Location.....................	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487).........	Low Plasticity Silt (ML)
Fill material description (ASTM D2487)......	Well Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure.....	8-inch lifts tamped with a pneumatic compactor

Figure C-2. Static Soil Test, Test No. MWP-1

Static Load Test Setup	Post-Test Photo of Post
	

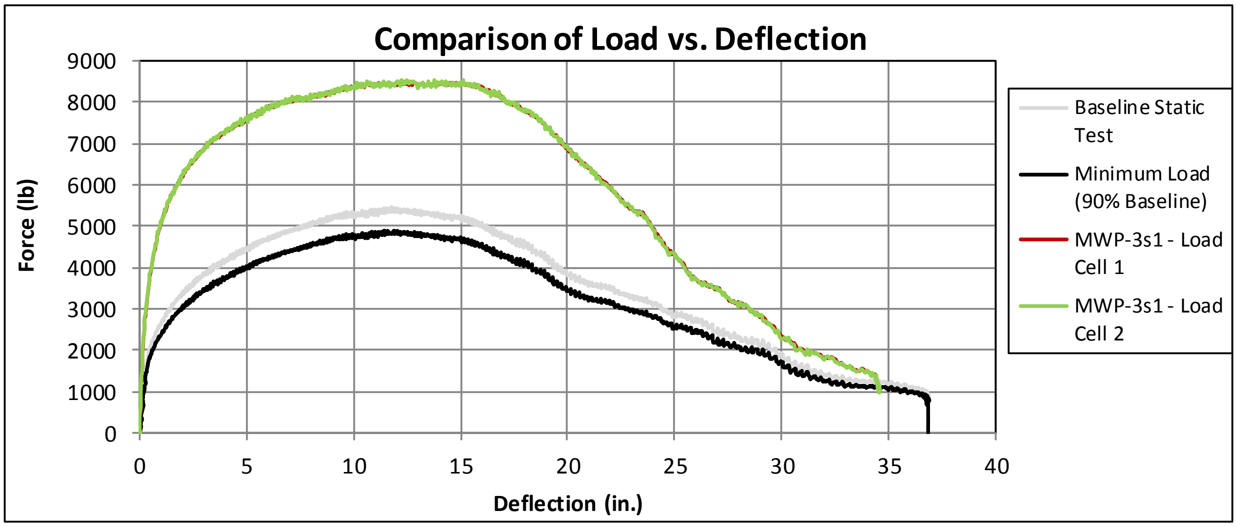


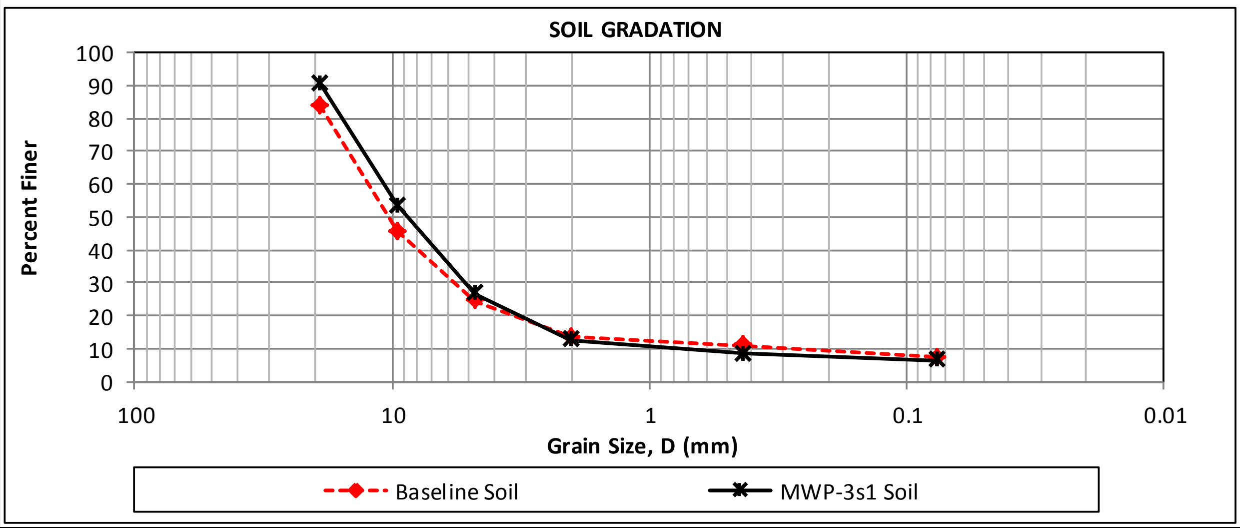


Date..	4/17/2014
Test Facility & Site Location.....................	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487).........	Well Graded Gravel (GW)
Fill material description (ASTM D2487)......	Well Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure.....	8-inch lifts tamped with a pneumatic compactor

Figure C-3. Static Soil Test, Test No. MWP-2

Static Load Test Setup	Post-Test Photo of Post
	





Date	7/11/2014
Test Facility & Site Location	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)	Well Graded Gravel (GW)
Fill material description (ASTM D2487)	Well Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure	8-inch lifts tamped with a pneumatic compactor

Figure C-4. Static Soil Test, Test No. MWP-3

Appendix D. Vehicle Deformation Records

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: MWP-1
VEHICLE: Taurus

Note: If impact is on driver side need to enter negative number for Y

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	27 1/4	-20 1/2	-6 1/2	27 1/4	-20 3/4	-6 1/4	0	- 1/4	1/4
2	29 1/2	-17	-9	29 1/2	-17 1/4	-8 3/4	0	- 1/4	1/4
3	28	-8 3/4	-9	28	-8 3/4	-9 1/4	0	0	- 1/4
4	27	-3 1/4	-9 1/4	27	-3 1/2	-9 1/2	0	- 1/4	- 1/4
5	24 1/4	-20 1/4	-10 1/2	24 1/4	-20 1/4	-10 1/2	0	0	0
6	24 3/4	-17 1/4	-11 1/2	24 3/4	-17 1/4	-11 1/2	0	0	0
7	25	-11	-11 1/4	25	-11	-11 1/4	0	0	0
8	24 3/4	-7	-11	25	-7	-11	1/4	0	0
9	22 1/2	-21 1/2	-11 3/4	22 1/2	-21 1/2	-11 3/4	0	0	0
10	21 3/4	-16	-11 3/4	21 3/4	-16 1/4	-11 3/4	0	- 1/4	0
11	21 1/4	-11 3/4	-11 1/4	21 1/4	-11 1/2	-11 1/2	0	1/4	- 1/4
12	21 1/4	-6 1/4	-11 1/4	21 1/4	-6 1/4	-11 1/2	0	0	- 1/4
13	20 1/2	- 3/4	-6 1/4	20 1/2	- 3/4	-6 1/4	0	0	0
14	15 1/4	-22	-11 1/4	15 1/4	-22	-11 1/4	0	0	0
15	15	-17	-10 3/4	15	-17 1/4	-10 3/4	0	- 1/4	0
16	15	-10 1/4	-10 1/2	15	-10 1/4	-10 1/2	0	0	0
17	13 3/4	-1 3/4	-5 3/4	13 3/4	-1 3/4	-5 3/4	0	0	0
18	11 3/4	-24 1/4	-10	11 3/4	-24 1/4	-10	0	0	0
19	10 3/4	-17 1/4	-10 1/4	10 3/4	-17 1/4	-10	0	0	1/4
20	10 1/4	-12 1/4	-10 1/4	10 1/4	-12 3/4	-10	0	- 1/2	1/4
21	9 3/4	-7 1/4	-9 3/4	10	-7 1/4	-9 3/4	1/4	0	0
22	9 1/4	-1 3/4	-5 1/2	9 1/4	-1 3/4	-5 1/2	0	0	0
23	5 3/4	-21	-9 1/2	5 3/4	-21	-9 1/2	0	0	0
24	6 1/4	-12 3/4	-9 1/2	6 1/4	-12 3/4	-9 1/2	0	0	0
25	6 1/2	-8 1/4	-8 1/2	6 1/2	-8 1/4	-8 1/2	0	0	0
26	2	-21 3/4	-8 1/4	2	-21 3/4	-8 1/4	0	0	0
27	2	-16	-7 3/4	2	-16	-7 3/4	0	0	0
28	1 1/2	-8 3/4	-6 3/4	1 1/2	-8 3/4	-6 3/4	0	0	0
29							0	0	0
30							0	0	0
31							0	0	0

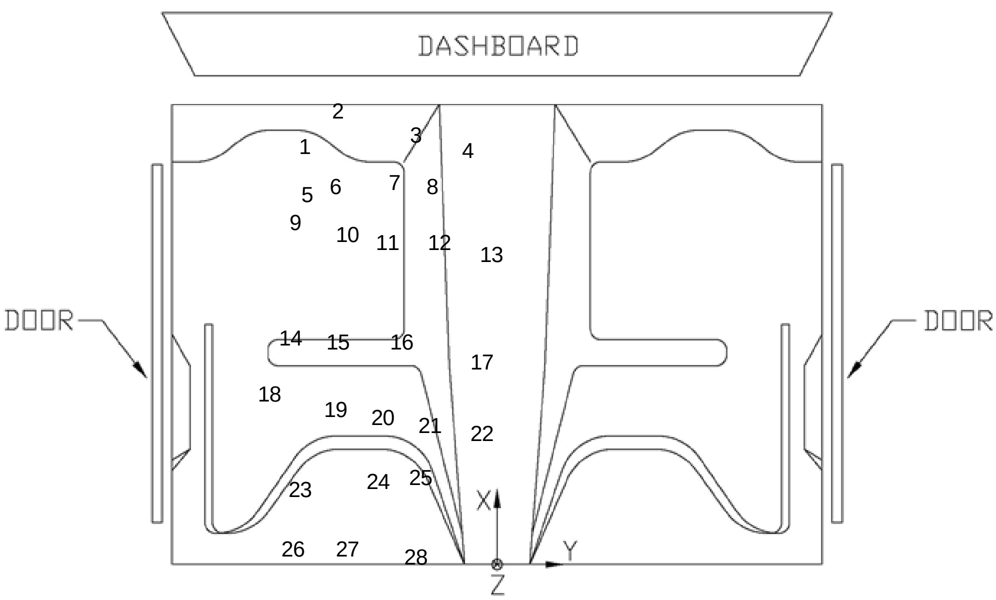


Figure D-1. Floorpan Deformation Data – Set 1, Test No. MWP-1

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

TEST: MWP-1
VEHICLE: Taurus

Note: If impact is on driver side need to enter negative number for Y

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	40 1/2	-24	-1 1/2	40 1/2	-24	-1 1/4	0	0	1/4
2	43	-20 3/4	-4	43	-21	-4	0	- 1/4	0
3	41 3/4	-11 3/4	-5	41 3/4	-12 1/2	-5	0	- 3/4	0
4	40 3/4	-6 3/4	-5 1/2	40 3/4	-7	-5 1/2	0	- 1/4	0
5	38	-23 3/4	-6 1/4	38	-23 3/4	-6 1/4	0	0	0
6	38 3/4	-20 1/4	-7 1/4	38 3/4	-20 1/2	-7	0	- 1/4	1/4
7	39	-14	-7	39	-14 1/4	-7	0	- 1/4	0
8	38 3/4	-10	-7	38 3/4	-10 1/4	-7	0	- 1/4	0
9	36 1/2	-24 3/4	-7 1/4	36 1/2	-25	-7 1/4	0	- 1/4	0
10	35 3/4	-19	-7 1/2	35 3/4	-19 1/2	-7 1/2	0	- 1/2	0
11	35 3/4	-14 1/2	-7 1/2	35 1/4	-15	-7 1/2	- 1/2	- 1/2	0
12	35 3/4	-9 3/4	-7 3/4	35 1/4	-9 1/2	-7 3/4	- 1/2	1/4	0
13	34 1/4	-4	-2 3/4	34	-4	-2 3/4	- 1/4	0	0
14	29 1/4	-25 1/2	-7 1/4	29 1/2	-25 1/2	-7 1/4	1/4	0	0
15	29 1/4	-19 3/4	-7 1/4	29 1/4	-20 1/2	-7	0	- 3/4	1/4
16	29	-13	-7 1/4	29	-13 1/2	-7	0	- 1/2	1/4
17	27 3/4	-5 1/4	-3	27 3/4	-5 1/4	-3	0	0	0
18	25 3/4	-27 1/2	-6 1/2	25 3/4	-27 1/2	-6 1/4	0	0	1/4
19	25	-20	-7	25	-20 1/4	-6 3/4	0	- 1/4	1/4
20	24 1/2	-15 1/2	-7 1/4	24 1/2	-15 1/2	-7	0	0	1/4
21	24	-10	-7 1/4	24	-10 1/4	-7 1/4	0	- 1/4	0
22	23 1/4	-5 1/4	-3	23 1/4	-5 1/4	-3	0	0	0
23	20	-24 1/4	-6 1/2	20	-24 1/4	-6 1/2	0	0	0
24	20 1/2	-15 3/4	-7	20 1/4	-16	-7	- 1/4	- 1/4	0
25	20 1/2	-11 1/4	-6	20 1/2	-11 1/2	-6	0	- 1/4	0
26	16	-25 1/4	-5 1/2	16	-25 1/4	-5 1/2	0	0	0
27	16 1/4	-19 1/2	-5 1/2	16	-19 1/2	-5 1/4	- 1/4	0	1/4
28	15 1/2	-12 1/2	-5	15 1/2	-12 1/2	-4 3/4	0	0	1/4
29							0	0	0
30							0	0	0
31							0	0	0

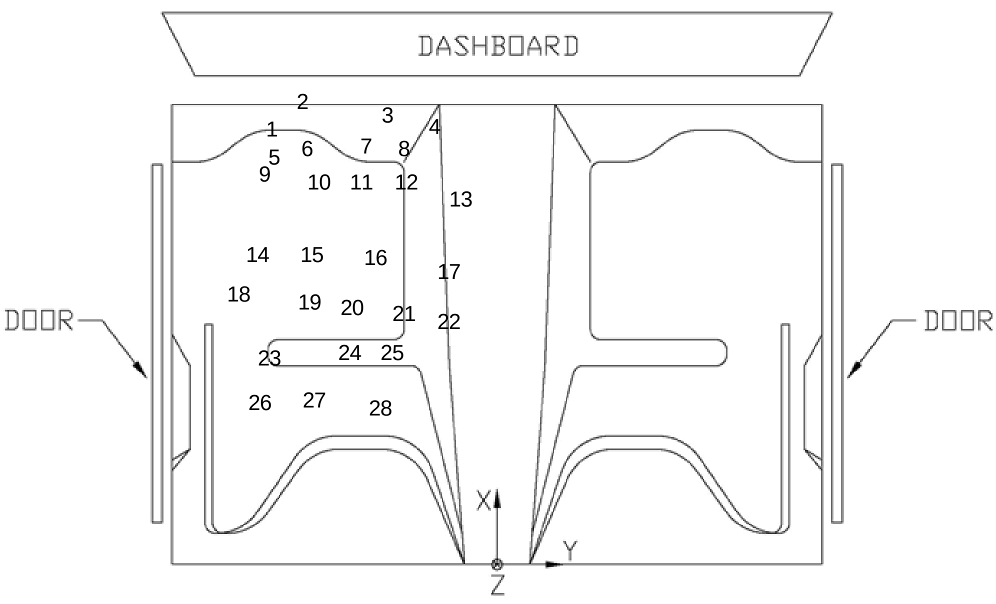


Figure D-2. Floorpan Deformation Data – Set 2, Test No. MWP-1

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

TEST: MWP-1
VEHICLE: Taurus

Note: If impact is on driver side need to enter negative number for Y

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	A1	34 1/4	-49 3/4	19 3/4	34 1/2	-50	19 1/2	1/4	- 1/4	- 1/4
	A2	35	-33 1/4	20 1/2	35 1/4	-33 1/4	20 1/4	1/4	0	- 1/4
	A3	35 3/4	-28 1/4	20 1/4	35	-28 1/4	20	- 3/4	0	- 1/4
	A4	31	-54 1/2	16 1/2	31 1/4	-54 3/4	16 1/4	1/4	- 1/4	- 1/4
	A5	30	-35 1/4	15 1/4	30 3/4	-35 1/4	15	3/4	0	- 1/4
	A6	30 1/4	-29 3/4	15 3/4	30 1/4	-29 3/4	15 1/4	0	0	- 1/2
SIDE PANEL	B1	25 1/4	-24 3/4	-6 1/4	25 1/2	-24 3/4	-6 1/4	1/4	0	0
	B2	27 1/2	-23	-6 3/4	27 1/2	-23	-6 3/4	0	0	0
	B3	23	-24 1/2	-9 1/4	23	-24 1/2	-9 1/4	0	0	0
IMPACT SIDE DOOR	C1	9 3/4	-37 3/4	18	10	-37 3/4	18	1/4	0	0
	C2	14 3/4	-35 1/2	17 1/4	14 3/4	-35 1/2	17	0	0	- 1/4
	C3	24 3/4	-35	15 3/4	24 3/4	-35	16	0	0	1/4
	C4	15 3/4	-28 3/4	1 3/4	15 1/2	-28 1/2	1 3/4	- 1/4	1/4	0
	C5	19 3/4	-29	5 1/2	19 1/2	-29	5 1/2	- 1/4	0	0
	C6	23 3/4	-28 1/2	3	23 1/2	-28 1/4	3	- 1/4	1/4	0
ROOF	D1							0	0	0
	D2							0	0	0
	D3							0	0	0
	D4							0	0	0
	D5							0	0	0
	D6							0	0	0
	D7							0	0	0
	D8							0	0	0
	D9							0	0	0
	D10							0	0	0
	D11							0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

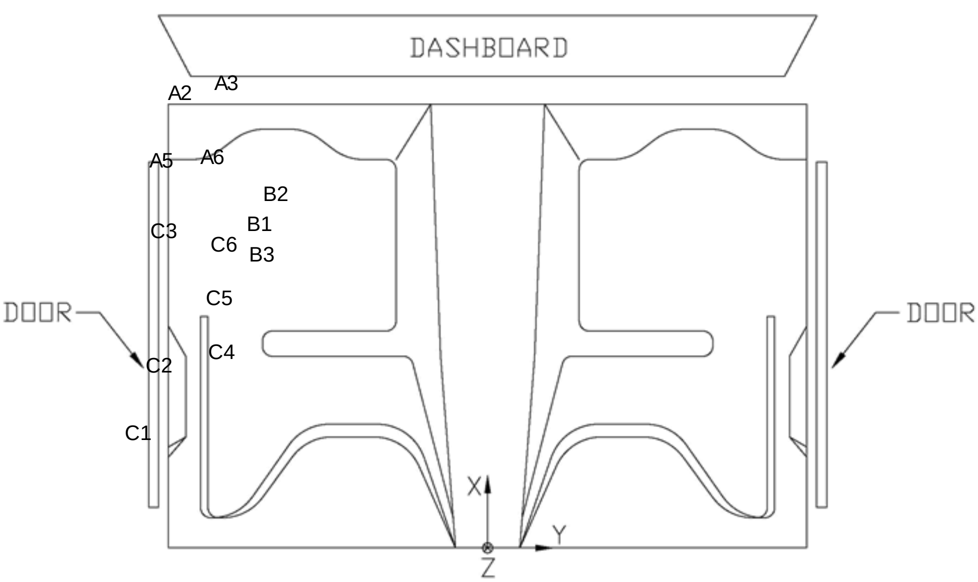


Figure D-3. Occupant Compartment Deformation Data – Set 1, Test No. MWP-1

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: MWP-1
VEHICLE: Taurus

Note: If impact is on driver side need to enter negative number for Y

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	A1	49 3/4	-49	23	49 3/4	-49	23	0	0	0
	A2	50 3/4	-32 1/2	23 1/2	51	-32 1/2	23 1/4	1/4	0	- 1/4
	A3	50 3/4	-27 1/2	22 3/4	50 3/4	-27 1/2	22 1/2	0	0	- 1/4
	A4	47 1/2	-53 3/4	20	47 1/2	-53 1/2	20	0	1/4	0
	A5	47 1/4	-32 1/4	18	47	-32 1/4	18	- 1/4	0	0
	A6	46 3/4	-29	17 3/4	46 3/4	-29	17 3/4	0	0	0
SIDE PANEL	B1	36 1/2	-29 1/2	-1 1/4	36 3/4	-29 1/4	-1 1/4	1/4	1/4	0
	B2	38 3/4	-27 1/2	-2 1/4	38 3/4	-27 1/4	-2 1/4	0	1/4	0
	B3	34 3/4	-29 1/2	-4 1/2	34 3/4	-29 1/2	-4 1/2	0	0	0
IMPACT SIDE DOOR	C1	14	-39 1/4	20 1/2	14	-39 3/4	20 1/2	0	- 1/2	0
	C2	19	-39 1/4	20	18 3/4	-39 3/4	20	- 1/4	- 1/2	0
	C3	29	-39	19 1/2	28 3/4	-39	18 3/4	- 1/4	0	- 3/4
	C4	22 1/2	-33 1/2	5	22 1/4	-33 1/2	5	- 1/4	0	0
	C5	26	-34 1/4	8 3/4	26	-34 1/4	8 3/4	0	0	0
	C6	30 1/4	-33 1/2	6 3/4	30	-33 1/4	6 3/4	- 1/4	1/4	0
ROOF	D1							0	0	0
	D2							0	0	0
	D3							0	0	0
	D4							0	0	0
	D5							0	0	0
	D6							0	0	0
	D7							0	0	0
	D8							0	0	0
	D9							0	0	0
	D10							0	0	0
	D11							0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

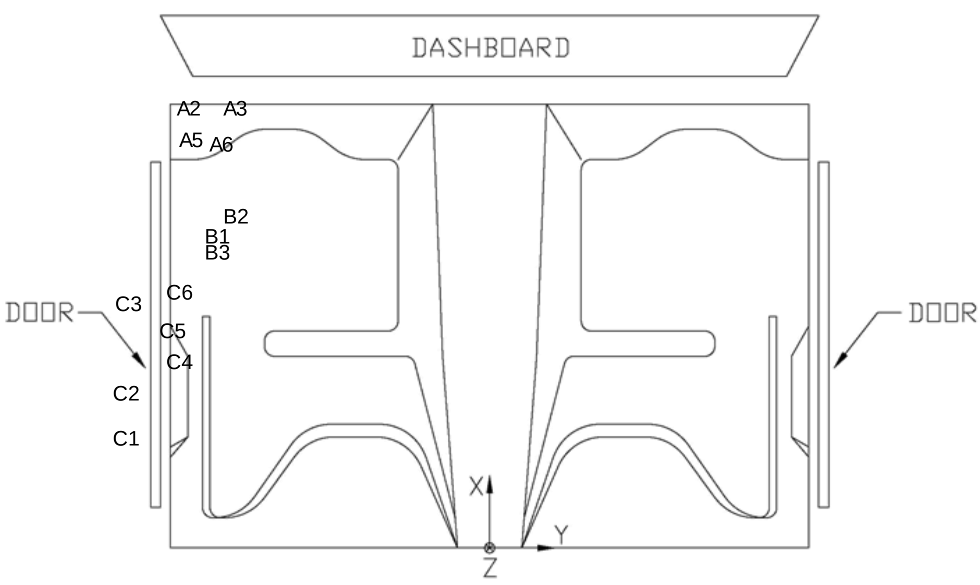
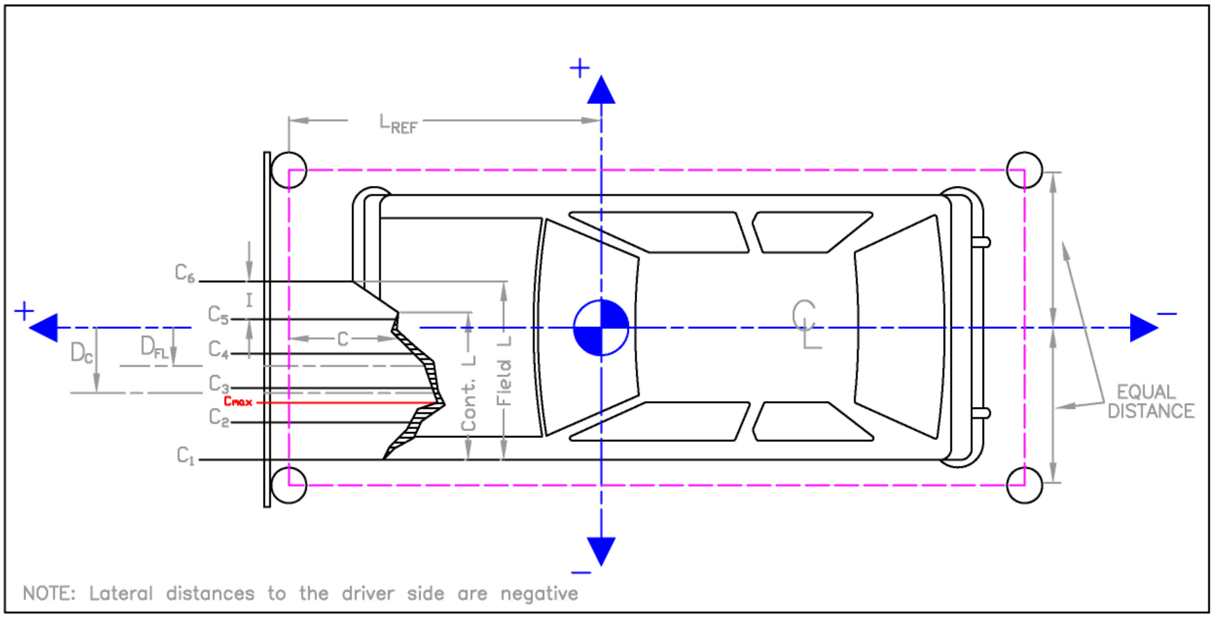


Figure D-4. Occupant Compartment Deformation Data – Set 2, Test No. MWP-1

Date: 3/26/2014 **Test Number:** MWP-1

Make: FORD **Model:** Taurus **Year:** 2006



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	89	(2261)
Width of contact and induced crush - Field L:	68 3/4	(1746)
Crush measurement spacing interval (L/5) - I:	13.75	(349)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	68 3/4	(1746)
Distance from center of vehicle to center of contect damage - D_C:	0	()

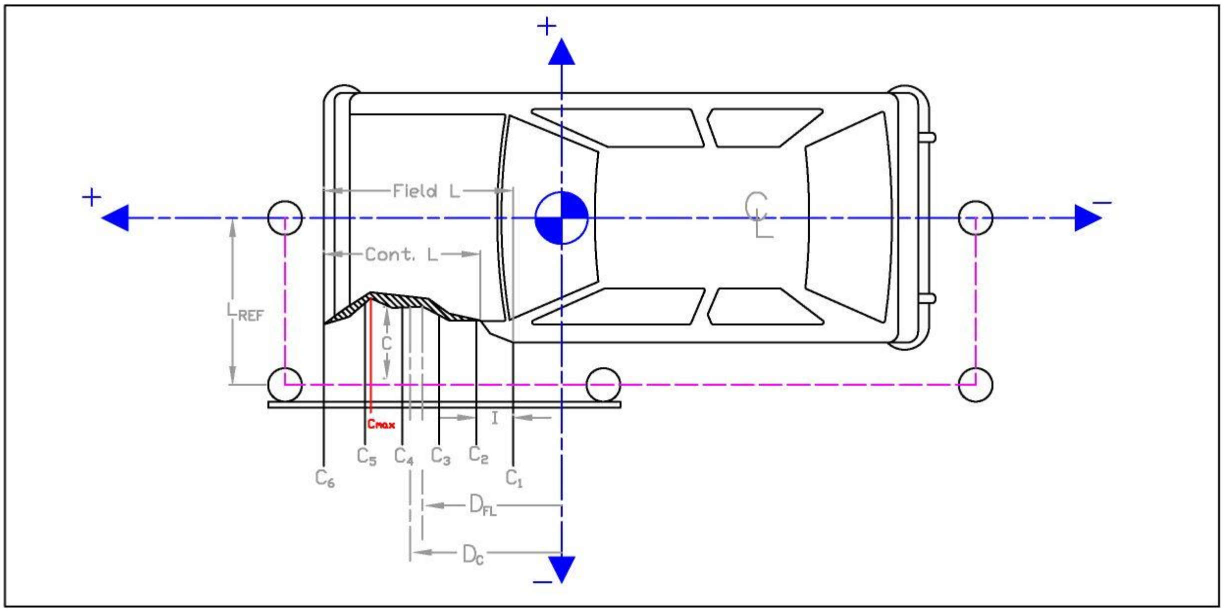
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)

	Crush Measurement		Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	na	NA	-34 3/8	-(873)	32 3/4	(832)	6/7	(22)	NA	NA
C_2	7 1/2	(191)	-20 5/8	-(524)	9 1/2	(242)			-2 8/9	-(73)
C_3	5 1/4	(133)	-6 7/8	-(175)	6 2/3	(170)			-2 2/7	-(58)
C_4	5 3/4	(146)	6 7/8	(175)	6 5/7	(170)			-1 4/5	-(46)
C_5	8 3/4	(222)	20 5/8	(524)	9 4/9	(240)			-1 1/2	-(39)
C_6	24 1/4	(616)	34 3/8	(873)	32 3/4	(832)			-9 1/3	-(238)
C_{MAX}	24 1/4	(616)	34 3/8	(873)	32 3/4	(832)			-9 1/3	-(238)

Figure D-5. Exterior Vehicle Crush (NASS) - Front, Test No. MWP-1

Date: 3/26/2014 **Test Number:** MWP-1

Make: FORD **Model:** Taurus **Year:** 2006



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	41	(1041)
Width of contact and induced crush - Field L:	197 3/4	(5023)
Crush measurement spacing interval (L/5) - I:	39.55	(1005)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-16.875	-(429)
Width of Contact Damage:	197 3/4	(5023)
Distance from vehicle c.g. to center of contect damage - D_C:	16 7/8	(429)

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been remeoved)

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	na	NA	-115 3/4	-(2940)	12 1/8	(308)	-2	-(51)	NA	NA
C_2	5 3/4	(146)	-76 1/5	-(1935)	8 5/8	(219)			- 7/8	-(22)
C_3	4 3/8	(111)	-36 2/3	-(931)	6 3/4	(171)			- 3/8	-(10)
C_4	4	(102)	2 8/9	(74)	7	(175)			-1	-(23)
C_5	6 1/2	(165)	42 4/9	(1078)	8 1/8	(206)			3/8	(10)
C_6	na	NA	82	(2083)	8 1/8	(206)			NA	NA
C_{MAX}	8 1/2	(216)	24	(610)	7 1/2	(191)			3	(76)

Figure D-6. Exterior Vehicle Crush (NASS) - Side, Test No. MWP-1

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: MWP-2
VEHICLE: Ram 1500

Note: If impact is on driver side need to enter negative number for Y

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	27 3/4	-28 1/4	0	27 3/4	-28 1/2	0	0	- 1/4	0
2	29 1/2	-23	-1	29 1/2	-23 1/2	-1	0	- 1/2	0
3	28 1/2	-16	-2	28 1/2	-16 3/4	-2	0	- 3/4	0
4	27 1/4	-9 1/2	-2	27 1/2	-9 3/4	-2	1/4	- 1/4	0
5	23 3/4	-27	-4 1/4	24	-26 3/4	-4	1/4	1/4	1/4
6	23 1/2	-20 1/4	-4 1/2	23 1/2	-20 3/4	-4 1/2	0	- 1/2	0
7	24	-15 1/2	-4 1/4	24	-15 1/2	-4 1/4	0	0	0
8	24	-10	-4 1/4	23 3/4	-10 1/2	-4 1/2	- 1/4	- 1/2	- 1/4
9	20	-26 1/2	-6	20 1/4	-26 3/4	-6	1/4	- 1/4	0
10	20 1/4	-21 3/4	-6	20 1/4	-21 1/2	-6	0	1/4	0
11	20 1/4	-16	-6	20 1/4	-16	-6 1/4	0	0	- 1/4
12	20 3/4	-10	-6	20 3/4	-10 1/4	-6 1/4	0	- 1/4	- 1/4
13	17	-27	-6 1/4	17 1/4	-26 3/4	-6 1/4	1/4	1/4	0
14	16 1/2	-21 3/4	-6 1/4	16 1/2	-21 3/4	-6 1/4	0	0	0
15	16 3/4	-16 1/2	-6 1/4	16 3/4	-16 3/4	-6 1/4	0	- 1/4	0
16	16 3/4	-10 3/4	-6 1/4	16 3/4	-11	-6 1/2	0	- 1/4	- 1/4
17	13 3/4	-12 1/2	- 1/4	14	-6	1/4	1/4	6 1/2	1/2
18	11 1/2	-27 1/4	-6 1/4	11 1/4	-27	-6 1/2	- 1/4	1/4	- 1/4
19	11 1/2	-23 1/2	-6 1/4	11 1/2	-23 1/4	-6 1/4	0	1/4	0
20	11 1/2	-19 3/4	-6 1/4	11 1/2	-19 1/2	-6 1/4	0	1/4	0
21	11 1/2	-15 3/4	-6 1/4	11 1/2	-15 3/4	-6 1/4	0	0	0
22	11 1/2	-11	-6 1/4	11 1/2	-11	-6 1/2	0	0	- 1/4
23	8 3/4	-5 1/2	- 1/4	9	-5 1/2	- 1/4	1/4	0	0
24	1	-27	-2 3/4	1	-26 3/4	-2 3/4	0	1/4	0
25	1	-23	-2 1/2	1	-22 3/4	-2 3/4	0	1/4	- 1/4
26	1	-17 1/2	-2 1/2	1	-17	-2 3/4	0	1/2	- 1/4
27	1	-12 1/2	-2 3/4	1	-12 1/2	-3	0	0	- 1/4
28	1 1/2	-5 1/4	- 1/4	1 1/2	-5 1/2	- 1/4	0	- 1/4	0
29							0	0	0
30							0	0	0
31							0	0	0

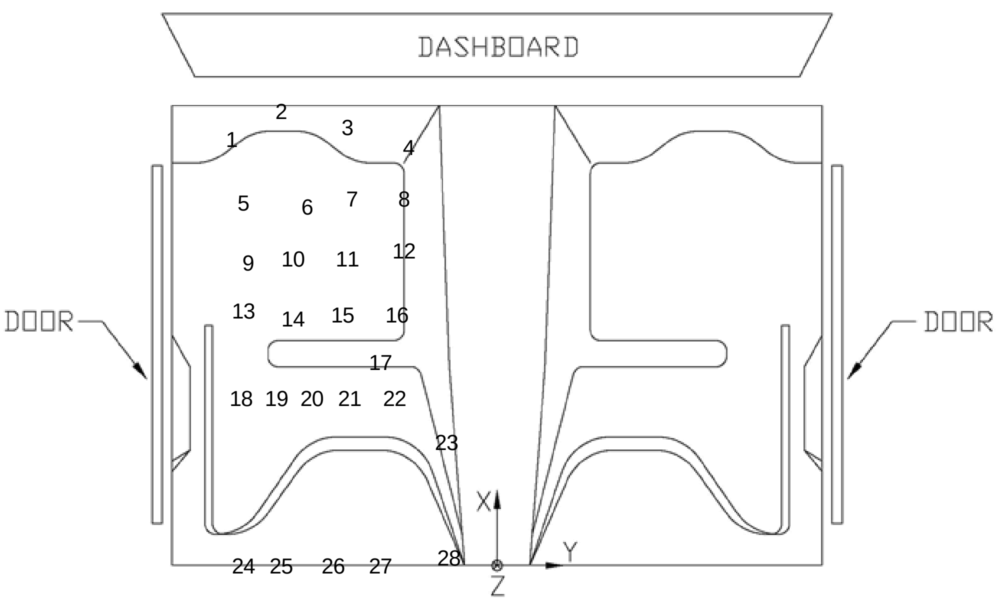


Figure D-7. Floorpan Deformation Data – Set 1, Test No. MWP-2

TEST: MWP-2
VEHICLE: Ram 1500

Note: If impact is on driver side need to enter negative number for Y

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	43 1/2	-35	-3	43 1/2	-35	-3	0	0	0
2	45 1/4	-29 3/4	-4 1/4	45 1/2	-30	-4 1/4	1/4	- 1/4	0
3	44 1/4	-22 1/2	-5	44 1/2	-23	-5 1/4	1/4	- 1/2	- 1/4
4	43 1/4	-16 1/2	-5 1/4	43 1/4	-17 1/4	-5 1/4	0	- 3/4	0
5	39 3/4	-34	-7	40	-34	-7	1/4	0	0
6	39 1/4	-27	-7 1/4	39 1/2	-27 1/4	-7 1/4	1/4	- 1/4	0
7	39 3/4	-22	-7 1/4	40	-22 1/2	-7 1/4	1/4	- 1/2	0
8	39 3/4	-17	-7 1/4	39 3/4	-17 1/4	-7 1/2	0	- 1/4	- 1/4
9	36	-33	-8 3/4	36 1/4	-33 1/4	-8 3/4	1/4	- 1/4	0
10	36 1/4	-28 1/2	-8 3/4	36 1/4	-28 1/4	-8 3/4	0	1/4	0
11	36	-22 1/2	-8 3/4	36 1/4	-22 1/2	-8 3/4	1/4	0	0
12	36 3/4	-17	-8 3/4	36 3/4	-17 1/4	-8 3/4	0	- 1/4	0
13	33	-34	-8 3/4	33 1/4	-34	-8 3/4	1/4	0	0
14	32 1/2	-28 1/2	-8 1/2	32 3/4	-28 1/2	-8 3/4	1/4	0	- 1/4
15	32 1/2	-23 1/4	-8 1/2	32 3/4	-23 1/4	-8 3/4	1/4	0	- 1/4
16	32 1/2	-17 1/4	-8 3/4	32 3/4	-17 1/2	-9	1/4	- 1/4	- 1/4
17	29 1/2	-12 3/4	-1 3/4	29 1/2	-12 3/4	-2	0	0	- 1/4
18	27 1/4	-34	-8 1/2	27 1/2	-33 3/4	-8 1/2	1/4	1/4	0
19	27 1/4	-30 1/4	-8 1/4	27 3/4	-30	-8 1/2	1/2	1/4	- 1/4
20	27 1/4	-26 1/4	-8 1/4	27 1/2	-26 1/2	-8 1/2	1/4	- 1/4	- 1/4
21	27 1/4	-22 1/2	-8 1/4	27 1/2	-22 3/4	-8 1/2	1/4	- 1/4	- 1/4
22	27 1/2	-17 1/2	-8 1/2	27 1/2	-18	-8 3/4	0	- 1/2	- 1/4
23	25 1/2	-12 1/4	-2 1/4	24 1/2	-12 1/4	-2 1/2	-1	0	- 1/4
24	17	-33 3/4	-4 1/2	17	-33 3/4	-4 1/2	0	0	0
25	16 3/4	-30	-4 1/4	17	-29 3/4	-4 1/4	1/4	1/4	0
26	17	-24 1/4	-5 1/4	17	-24	-4 1/2	0	1/4	3/4
27	17	-19 1/2	-4 1/4	17	19 1/2	-4 1/2	0	39	- 1/4
28	17 1/4	-12 1/4	-1 3/4	17 1/4	-12 1/4	-2	0	0	- 1/4
29							0	0	0
30							0	0	0
31							0	0	0

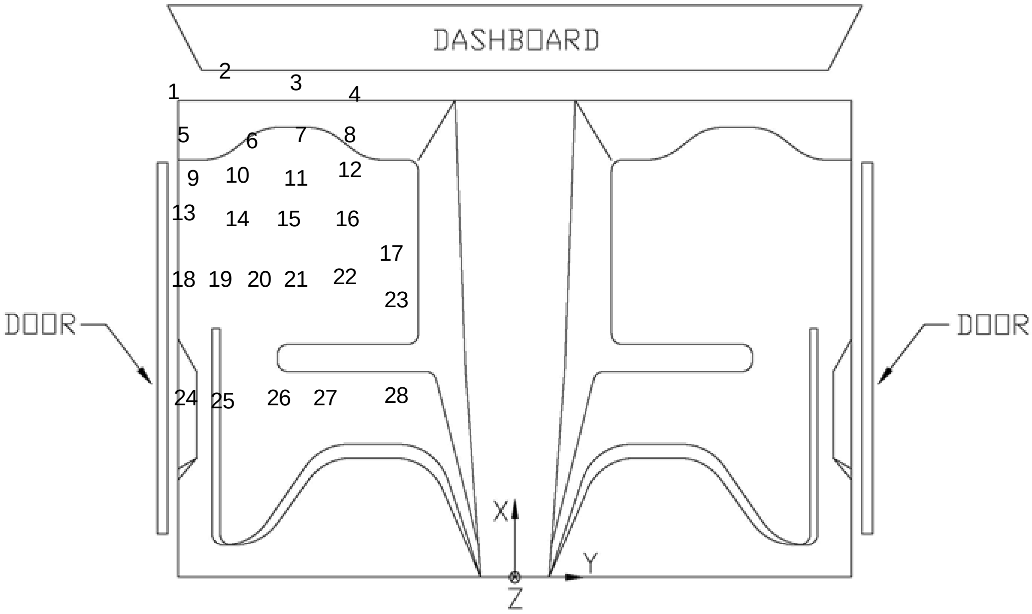


Figure D-8. Floorpan Deformation Data – Set 2, Test No. MWP-2

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

TEST: MWP-2
VEHICLE: Ram 1500

Note: If impact is on driver side need to enter negative number for Y

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	A1	40 1/4	-54 3/4	27	40 3/4	-55	27	1/2	- 1/4	0
	A2	39 1/2	-41 3/4	26 1/2	39 3/4	-42	26 1/2	1/4	- 1/4	0
	A3	39 1/2	-31	27 1/4	40	-31	27	1/2	0	- 1/4
	A4	35 3/4	-61 3/4	21	35 3/4	-61 1/2	20 3/4	0	1/4	- 1/4
	A5	35	-41 1/4	20 3/4	35	-41 1/4	20 1/2	0	0	- 1/4
	A6	33 1/2	-34 1/4	19 1/2	33 3/4	-34 1/4	19 1/4	1/4	0	- 1/4
SIDE PANEL	B1	19 1/2	-25 1/2	3 3/4	19 1/2	-25 3/4	3 3/4	0	- 1/4	0
	B2	21 1/4	-26	2	21 1/4	-26 1/4	2	0	- 1/4	0
	B3	19 1/4	-25 3/4	0	19 1/2	-26	0	1/4	- 1/4	0
IMPACT SIDE DOOR	C1	9 1/2	-41	21	9 1/4	-41	20 3/4	- 1/4	0	- 1/4
	C2	15 3/4	-39 1/2	20 3/4	15 1/2	-39 3/4	20 3/4	- 1/4	- 1/4	0
	C3	23 1/4	-39	20 3/4	23	-39 1/4	20 1/2	- 1/4	- 1/4	- 1/4
	C4	18 3/4	-32 1/2	3 3/4	18 1/2	-33 1/4	3 3/4	- 1/4	- 3/4	0
	C5	20 1/2	-32 1/4	- 3/4	20 1/4	-32 1/4	-1	- 1/4	0	- 1/4
	C6	23	-32 3/4	5	22 3/4	-32 3/4	5	- 1/4	0	0
ROOF	D1							0	0	0
	D2							0	0	0
	D3							0	0	0
	D4							0	0	0
	D5							0	0	0
	D6							0	0	0
	D7							0	0	0
	D8							0	0	0
	D9							0	0	0
	D10							0	0	0
	D11							0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

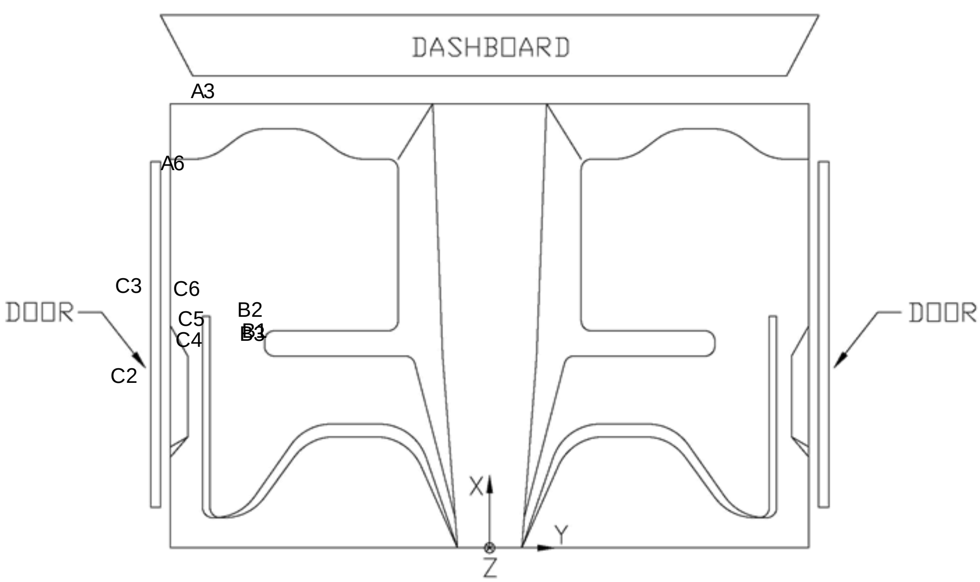


Figure D-9. Occupant Compartment Deformation Data – Set 1, Test No. MWP-2

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: MWP-2
VEHICLE: Ram 1500

Note: If impact is on driver side need to enter negative number for Y

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	A1	56 3/4	-54 1/2	24 3/4	56 3/4	-54 1/2	25 1/4	0	0	1/2
	A2	52 1/4	-41 1/2	24 1/4	52 1/4	-41 1/2	24 3/4	0	0	1/2
	A3	49 1/4	-31	25	49 1/2	-31	25	1/4	0	0
	A4	53 1/2	-61 1/2	18 1/2	53 1/2	-61 1/4	18 3/4	0	1/4	1/4
	A5	48 3/4	-41 1/4	18 1/2	48 1/2	-41 1/4	18 3/4	- 1/4	0	1/4
	A6	44 1/2	-34 1/2	17 1/4	44 1/2	-34 1/2	17 1/4	0	0	0
SIDE PANEL	B1	36 3/4	-33	1	36 3/4	-33	1	0	0	0
	B2	39 1/4	-34	-1	39 1/4	-34	-1 1/4	0	0	- 1/4
	B3	37 3/4	-33 1/4	-3	38	-33 1/4	-2 3/4	1/4	0	1/4
IMPACT SIDE DOOR	C1	13	-45	19 1/4	12 1/2	-45	19 1/2	- 1/2	0	1/4
	C2	19 1/4	-45	19	18 3/4	-45	19 1/4	- 1/2	0	1/4
	C3	26 3/4	-44 3/4	18 1/2	26 1/4	-44 3/4	18 3/4	- 1/2	0	1/4
	C4	23 1/4	-39 3/4	1 3/4	23	-39 3/4	2	- 1/4	0	1/4
	C5	25 1/4	-39 3/4	-3	25 1/4	-39 3/4	-2 3/4	0	0	1/4
	C6	27 1/2	-39 3/4	3	27 1/4	-39 3/4	3	- 1/4	0	0
ROOF	D1							0	0	0
	D2							0	0	0
	D3							0	0	0
	D4							0	0	0
	D5							0	0	0
	D6							0	0	0
	D7							0	0	0
	D8							0	0	0
	D9							0	0	0
	D10							0	0	0
	D11							0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

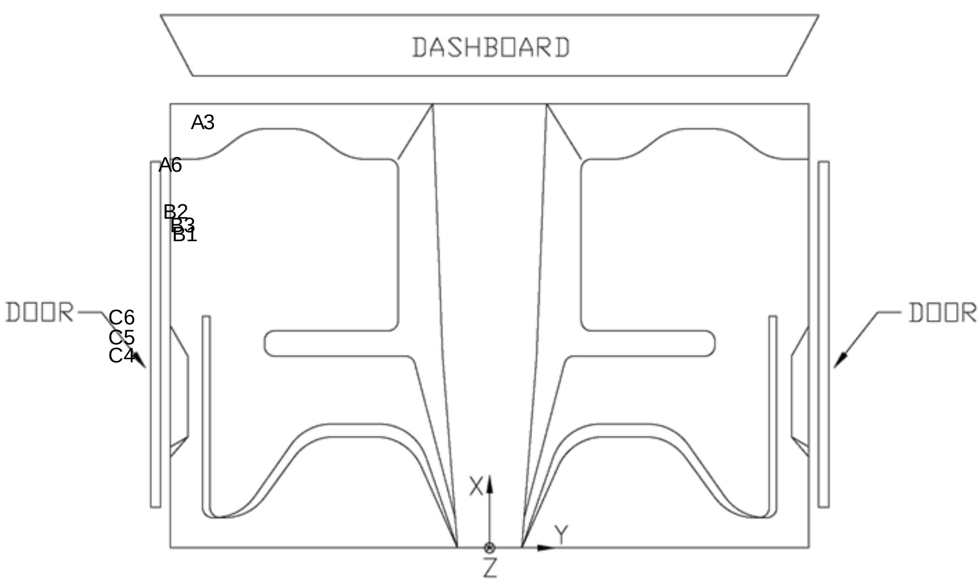
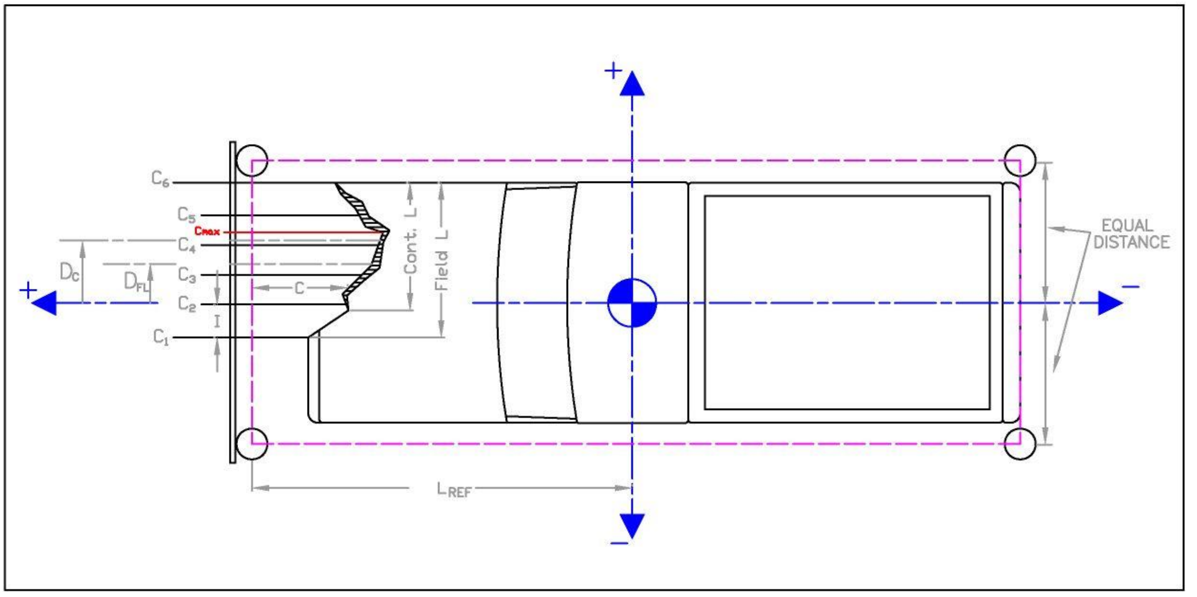


Figure D-10. Occupant Compartment Deformation Data – Set 2, Test No. MWP-2

Date: 8/18/2014 **Test Number:** MWP-2

Make: Dodge **Model:** Ram 1500 **Year:** 2008



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	103 1/2	(2629)
Width of contact and induced crush - Field L:	22 7/8	(581)
Crush measurement spacing interval (L/5) - I:	4.575	(116)
Distance from center of vehicle to center of Field L - D_{FL}:	-27.4375	-(697)
Width of Contact Damage:	15 7/8	(403)
Distance from center of vehicle to center of contect damage - D_C:	23	(584)

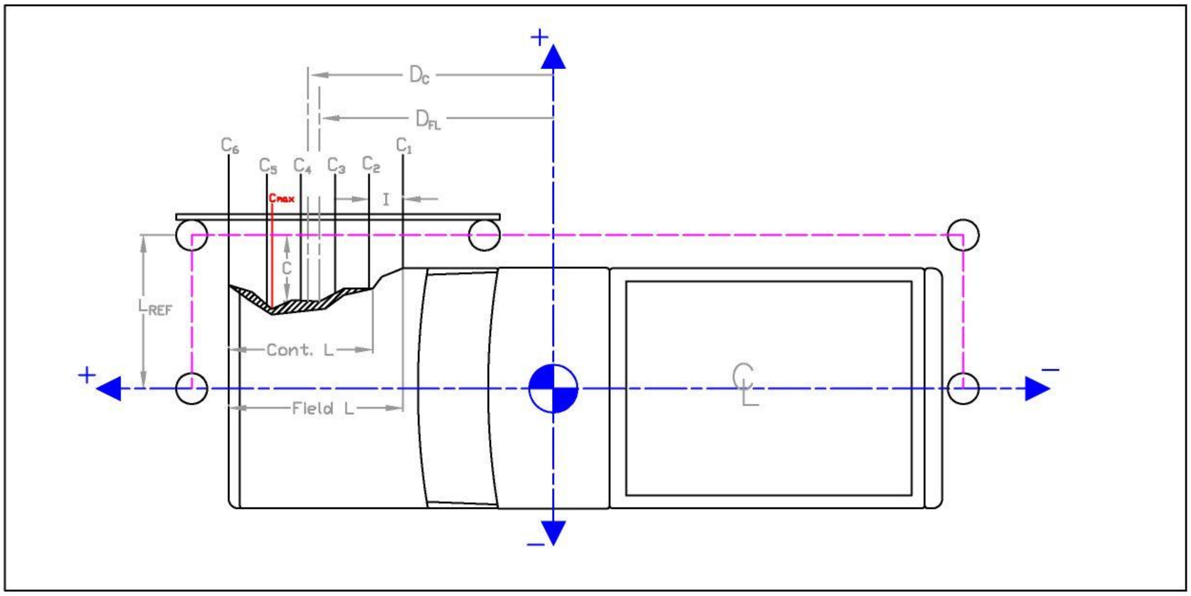
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)

	Crush Measurement		Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	na	NA	-38 7/8	-(987)	29	(737)	-7 3/8	-(187)	NA	NA
C_2	na	NA	-34 2/7	-(871)	20	(506)			NA	NA
C_3	18	(457)	-29 5/7	-(755)	16	(407)			9 1/3	(238)
C_4	9 1/4	(235)	-25 1/7	-(639)	14 1/6	(360)			2 4/9	(62)
C_5	5 1/4	(133)	-20 4/7	-(523)	12 2/3	(322)			-0	-(2)
C_6	3 3/4	(95)	-16	-(406)	11 3/4	(298)			- 5/8	-(16)
C_{MAX}	18	(457)	-29 5/7	-(755)	16	(407)			9 1/3	(238)

Figure D-11. Exterior Vehicle Crush (NASS) - Front, Test No. MWP-2

Date: 8/18/2014 **Test Number:** MWP-2

Make: Dodge **Model:** Ram 1500 **Year:** 2008



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	42	(1067)
Width of contact and induced crush - Field L:	228 1/4	(5798)
Crush measurement spacing interval (L/5) - I:	45.65	(1160)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-9.75	-(248)
Width of Contact Damage:	228 1/4	(5798)
Distance from vehicle c.g. to center of contect damage - D_C:	9 3/4	(248)

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been remeoved)

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	na	NA	-123 7/8	-(3146)	37	(940)	-8	-(203)	NA	NA
C_2	6	(152)	-78 2/9	-(1987)	10 1/2	(267)			3 1/2	(89)
C_3	4	(102)	-32 4/7	-(827)	11 5/8	(295)			3/8	(10)
C_4	3 3/4	(95)	13	(332)	11 1/4	(286)			1/2	(13)
C_5	6 1/4	(159)	58 5/7	(1492)	10 1/2	(267)			3 3/4	(95)
C_6	na	NA	104 3/8	(2651)	37	(940)			NA	NA
C_{MAX}	13	(330)	88	(2235)	12 1/8	(308)			8 7/8	(225)

Figure D-12. Exterior Vehicle Crush (NASS) - Side, Test No. MWP-2

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: MWP-3
VEHICLE: 2270P

Note: If impact is on driver side need to enter negative number for Y

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	28	-26 1/2	-2 3/4	28 1/4	-26 3/4	-2 3/4	1/4	- 1/4	0
2	29	-22 1/2	-4	29	-22 1/2	-4	0	0	0
3	27	-16 1/2	-4 1/2	27	-17	-4 1/2	0	- 1/2	0
4	27	-10 1/2	-4	27	-10 3/4	-4	0	- 1/4	0
5	24	-27 1/2	-6 1/4	24	-27	-6 1/4	0	1/2	0
6	24	-22 3/4	-6 1/4	24	-22 1/2	-6 1/4	0	1/4	0
7	24	-15 1/4	-6	24	-15 1/4	-6	0	0	0
8	23 3/4	-10 1/4	-6	23 3/4	-10 1/4	-6	0	0	0
9	20 3/4	-27	-8	21	-26 3/4	-8	1/4	1/4	0
10	21	-22 1/4	-7 3/4	21	-22 1/4	-7 3/4	0	0	0
11	20 3/4	-16 1/4	-7 1/2	20 3/4	-16 1/4	-7 1/2	0	0	0
12	20 3/4	-10 1/2	-7 1/2	20 3/4	-10 3/4	-7 1/2	0	- 1/4	0
13	17 1/4	-27 1/4	-8	17 1/2	-27	-8	1/4	1/4	0
14	17 1/4	-22 1/4	-7 3/4	17 1/4	-22 1/4	-8	0	0	- 1/4
15	17 1/4	-16 1/2	-7 3/4	17 1/4	-16 1/2	-7 3/4	0	0	0
16	17 1/4	-10 3/4	-7 1/2	17 1/4	-11 1/2	-7 3/4	0	- 3/4	- 1/4
17	14 1/4	-5	- 1/2	14 1/4	-5 1/4	- 1/2	0	- 1/4	0
18	11 1/2	-27 1/4	-8	11 3/4	-27 1/4	-8	1/4	0	0
19	11 3/4	-22 1/4	-7 3/4	11 1/2	-21 1/4	-7 3/4	- 1/4	1	0
20	11 3/4	-18 1/4	-7 1/2	11 3/4	-18 1/2	-7 3/4	0	- 1/4	- 1/4
21	11 3/4	-14 1/4	-7 1/2	11 1/2	-15 1/4	-7 1/2	- 1/4	-1	0
22	11 1/2	-9 3/4	-7 1/4	11 1/2	-10 1/2	-7 1/2	0	- 3/4	- 1/4
23	11	-5 1/2	- 3/4	11	-5 1/2	- 3/4	0	0	0
24	1 1/2	-28	-4 1/2	1 1/4	-27 3/4	-4 3/4	- 1/4	1/4	- 1/4
25	1 1/4	-23 3/4	-3 3/4	1 1/4	-23 1/2	-3 3/4	0	1/4	0
26	1	-19 3/4	-3 1/2	1 1/4	-19 1/2	-3 3/4	1/4	1/4	- 1/4
27	1	-15 1/2	-3 1/2	1 1/4	-15 1/4	-3 1/2	1/4	1/4	0
28	1 3/4	-6 1/4	- 3/4	1 3/4	-6 1/4	-1	0	0	- 1/4
29							0	0	0
30							0	0	0
31							0	0	0

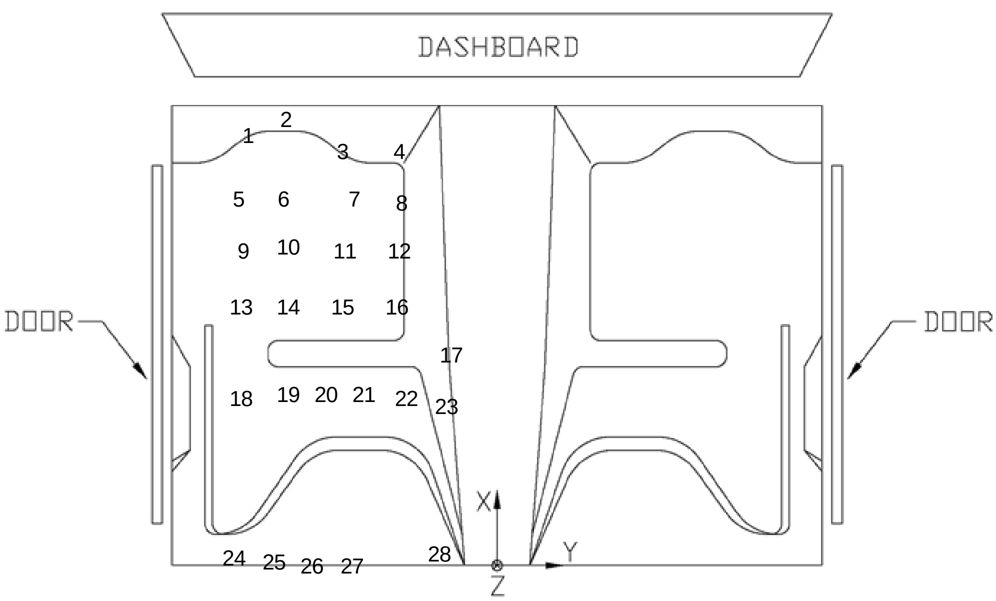


Figure D-13. Floorpan Deformation Data – Set 1, Test No. MWP-3

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

TEST: MWP-3
VEHICLE: 2270P

Note: If impact is on driver side need to enter negative number for Y

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	44	-32 3/4	-2 1/2	44 1/4	-33	-2 1/4	1/4	- 1/4	1/4
2	45 1/4	-28 1/4	-3 3/4	45 1/4	-28 3/4	-3 1/2	0	- 1/2	1/4
3	43 1/4	-22	-4 1/4	43 1/4	-22	-4 1/4	0	0	0
4	43 1/4	-16 1/2	-4	43 1/2	-17	-4	1/4	- 1/2	0
5	40 1/4	-33 3/4	-6	40 1/2	-33 1/2	-6	1/4	1/4	0
6	40 1/4	-29	-6	40 1/2	-28 3/4	-6	1/4	1/4	0
7	40 1/4	-21	-6	40 1/2	-21 1/4	-5 3/4	1/4	- 1/4	1/4
8	40 1/4	-16 1/2	-5 3/4	40 1/4	-16 1/2	-5 3/4	0	0	0
9	37 1/4	-33 1/2	-7 3/4	37 1/2	-33	-7 3/4	1/4	1/2	0
10	37 1/4	-29 1/4	-7 3/4	37 1/2	-28 1/2	-7 1/2	1/4	3/4	1/4
11	37 1/4	-22 1/4	-7 1/2	37 1/2	-22 1/2	-7 1/2	1/4	- 1/4	0
12	37 1/4	-17 1/4	-7 1/2	37 1/2	-16 3/4	-7 1/2	1/4	1/2	0
13	33 3/4	-33 3/4	-8	33 3/4	-33	-8	0	3/4	0
14	33 3/4	-28 1/4	-7 3/4	33 3/4	-28 1/2	-7 3/4	0	- 1/4	0
15	34	-22 1/2	-7 3/4	33 3/4	-22 3/4	-7 3/4	- 1/4	- 1/4	0
16	33 3/4	-16 3/4	-7 3/4	34	-17 1/2	-7 3/4	1/4	- 3/4	0
17	30 1/4	-11 1/4	- 1/2	30 1/2	-11 1/4	- 1/2	1/4	0	0
18	28	-33 1/2	-8	28	-33 1/2	-8	0	0	0
19	28	-28 1/4	-7 3/4	28	-28 1/2	-7 3/4	0	- 1/4	0
20	28	-24 1/2	-7 3/4	28	-24 3/4	-7 3/4	0	- 1/4	0
21	28	-21 1/4	-7 3/4	28 1/4	-21 1/2	-7 3/4	1/4	- 1/4	0
22	28	-16	-7 1/2	28	-16 3/4	-7 1/2	0	- 3/4	0
23	27	-11 1/2	-1	27 1/4	-11 3/4	-1	1/4	- 1/4	0
24	18	-34 1/4	-4 3/4	18	-33 3/4	-5	0	1/2	- 1/4
25	17 3/4	-30	-4 1/4	18	-29 3/4	-4 1/4	1/4	1/4	0
26	17 1/2	-26	-4	17 3/4	-25 3/4	-4 1/4	1/4	1/4	- 1/4
27	17 1/2	-21 3/4	-4	17 3/4	-21 1/4	-4	1/4	1/2	0
28	17 3/4	-12 1/2	-1 1/4	18	-12 1/4	-1 1/4	1/4	1/4	0
29							0	0	0
30							0	0	0
31							0	0	0

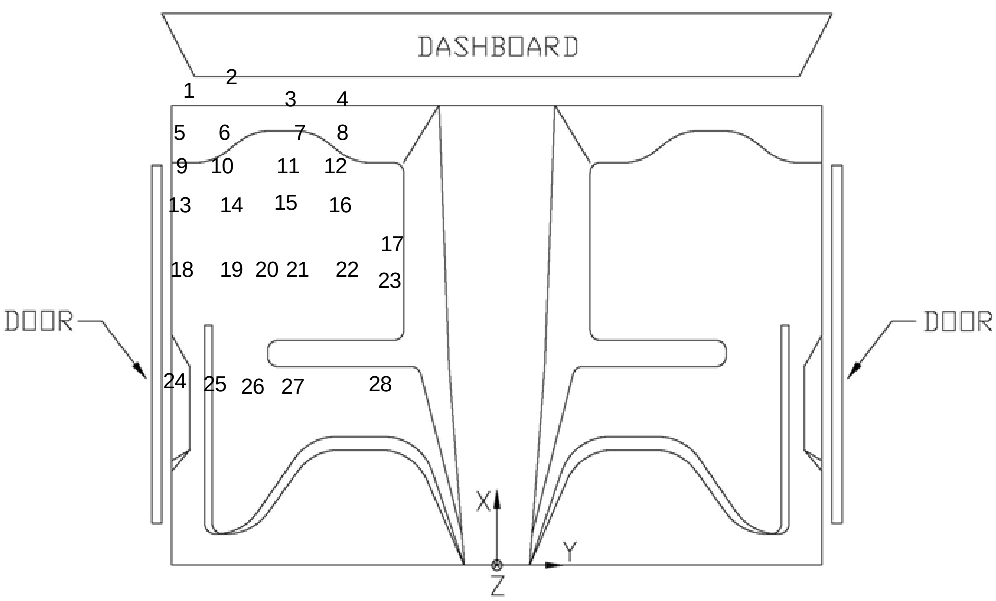


Figure D-14. Floorpan Deformation Data – Set 2, Test No. MWP-3

TEST: MWP-3
VEHICLE: 2270P

Note: If impact is on driver side need to enter negative number for Y

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	A1	39 1/2	-55 1/4	25 1/2	39 1/2	na	25 1/2	0	#VALUE!	0
	A2	38 1/2	-37	25 3/4	38 1/2	na	26	0	#VALUE!	1/4
	A3	38 1/2	-30 3/4	26 1/4	38 1/2	na	26 1/2	0	#VALUE!	1/4
	A4	35	-61 1/2	19	35	na	19 1/4	0	#VALUE!	1/4
	A5	33	-37 3/4	18 1/2	32 3/4	na	18 1/4	- 1/4	#VALUE!	- 1/4
	A6	32 1/2	-32 1/2	18 1/2	32 1/2	na	18 1/2	0	#VALUE!	0
SIDE PANEL	B1	19 3/4	-24 1/4	- 1/2	20	-24 1/4	- 1/2	1/4	0	0
	B2	23	-24 1/2	- 1/2	23	-24 3/4	- 1/2	0	- 1/4	0
	B3	21 1/4	-24 1/2	-3 3/4	21 1/4	-24 1/2	-3 3/4	0	0	0
IMPACT SIDE DOOR	C1	6 3/4	-37 3/4	19 3/4	6 1/2	-37 3/4	19 3/4	- 1/4	0	0
	C2	16 1/4	-36	19 1/2	16 1/4	-36	19 1/4	0	0	- 1/4
	C3	23 1/2	-39	19	23 1/2	-39	19	0	0	0
	C4	6 1/4	-30 1/2	4 1/4	6	-30 1/2	4	- 1/4	0	- 1/4
	C5	18 1/4	-28 3/4	2 1/4	18	-29	2 1/4	- 1/4	- 1/4	0
	C6	22 1/2	-32 3/4	3 3/4	22 1/2	-33	3 1/2	0	- 1/4	- 1/4
ROOF	D1							0	0	0
	D2							0	0	0
	D3							0	0	0
	D4							0	0	0
	D5							0	0	0
	D6							0	0	0
	D7							0	0	0
	D8							0	0	0
	D9							0	0	0
	D10							0	0	0
	D11							0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

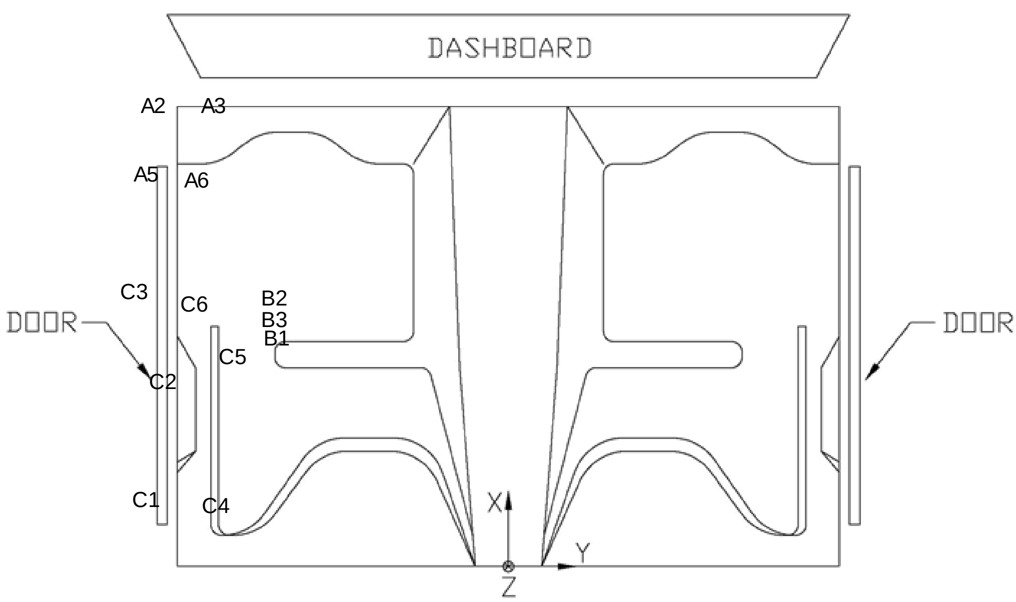


Figure D-15. Occupant Compartment Deformation Data – Set 1, Test No. MWP-3

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: MWP-3
VEHICLE: 2270P

Note: If impact is on driver side need to enter negative number for Y

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	A1	56	-55	25 1/4	56	na	na	0	#VALUE!	#VALUE!
	A2	51 3/4	-37 1/4	25 1/2	51 1/2	na	na	- 1/4	#VALUE!	#VALUE!
	A3	49 1/2	-31	26	49 1/4	na	na	- 1/4	#VALUE!	#VALUE!
	A4	52 3/4	-61 1/2	19	52 1/2	na	na	- 1/4	#VALUE!	#VALUE!
	A5	47	-38 1/4	18 1/2	46 3/4	na	na	- 1/4	#VALUE!	#VALUE!
	A6	44 1/2	-33 1/4	18 1/2	44 1/4	na	na	- 1/4	#VALUE!	#VALUE!
SIDE PANEL	B1	36 1/2	-24 3/4	- 1/4	36 1/2	-25	- 1/4	0	- 1/4	0
	B2	39 1/2	-25 3/4	- 1/4	39 1/2	-26	- 1/4	0	- 1/4	0
	B3	38 3/4	-25 1/4	-3 1/2	38 1/2	-25 1/2	-3 1/2	- 1/4	- 1/4	0
IMPACT SIDE DOOR	C1	10 1/2	-43 3/4	19 1/2	10	-43 3/4	19	- 1/2	0	- 1/2
	C2	20	-43 3/4	19 1/4	20	-43 1/2	19	0	1/4	- 1/4
	C3	27 1/4	-43 1/2	19	27	-43 1/4	18 3/4	- 1/4	1/4	- 1/4
	C4	11 1/2	-39	3 3/4	11 1/4	-39	3 3/4	- 1/4	0	0
	C5	23 1/2	-38 3/4	2	23 1/2	-38 3/4	2	0	0	0
	C6	27 3/4	-39	3 1/2	27 3/4	-38 3/4	3 1/2	0	1/4	0
ROOF	D1							0	0	0
	D2							0	0	0
	D3							0	0	0
	D4							0	0	0
	D5							0	0	0
	D6							0	0	0
	D7							0	0	0
	D8							0	0	0
	D9							0	0	0
	D10							0	0	0
	D11							0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

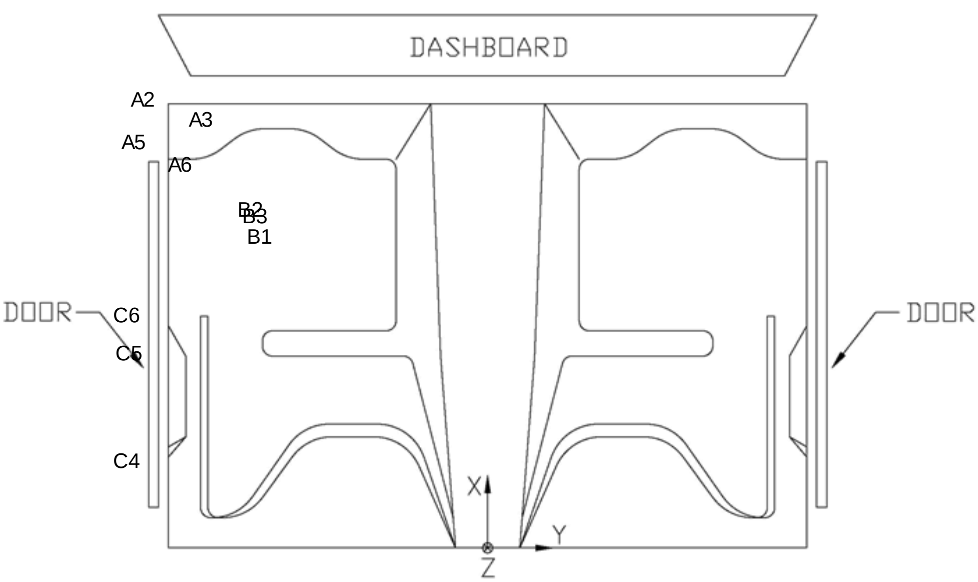
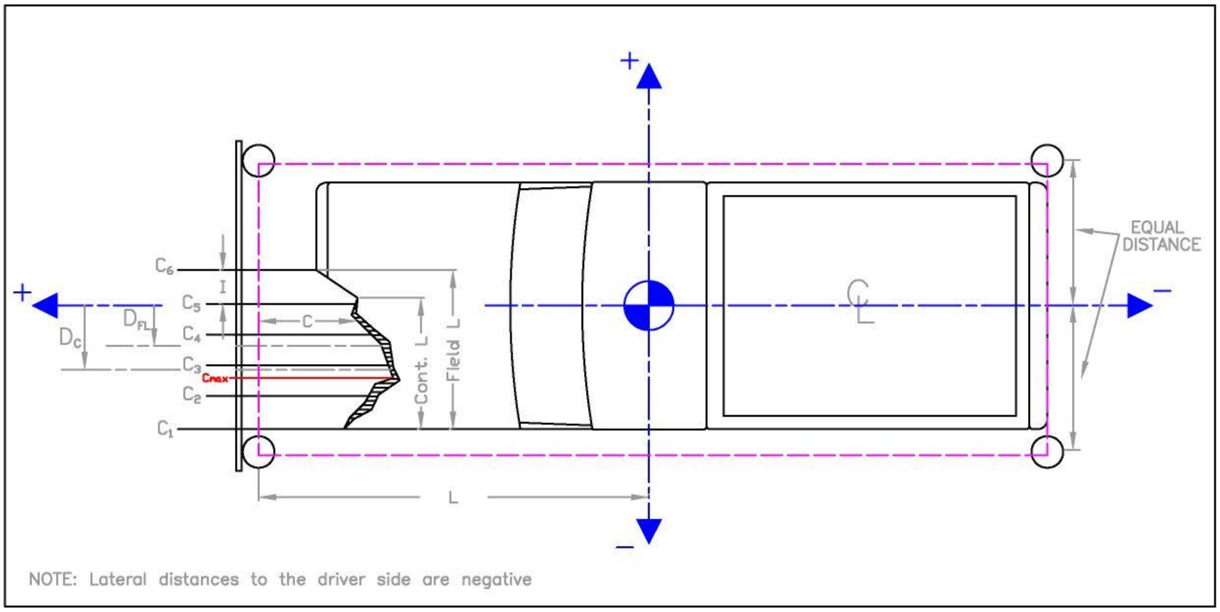


Figure D-16. Occupant Compartment Deformation Data – Set 2, Test No. MWP-3

Date: 8/20/2014 **Test Number:** MWP-3

Make: Dodge Ram **Model:** 2270P **Year:** 2007



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	108 1/4	(2750)
Width of contact and induced crush - Field L:	78	(1981)
Crush measurement spacing interval (L/5) - I:	15.6	(396)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	78	(1981)
Distance from center of vehicle to center of contect damage - D_C:	0	()

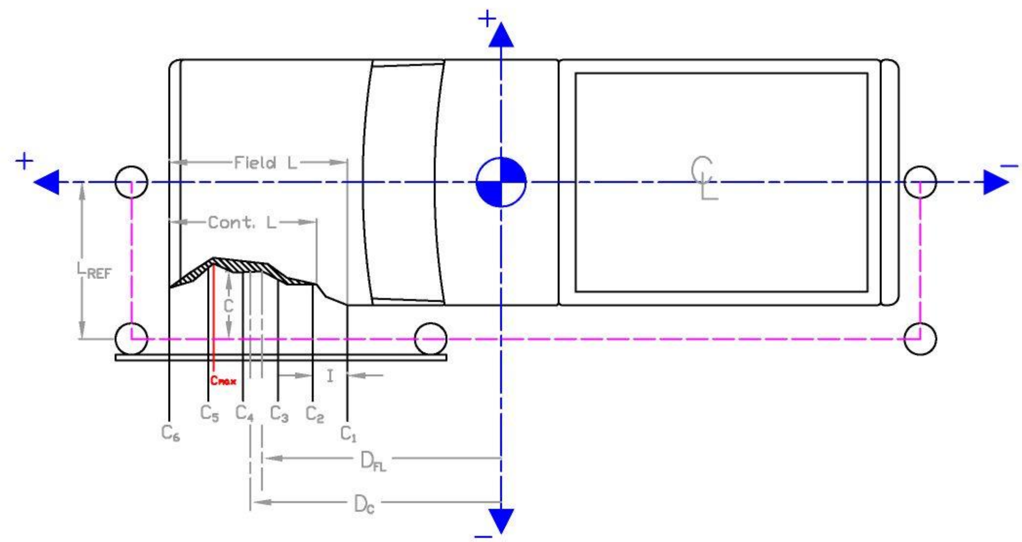
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)

	Crush Measurement in.	(mm)	Lateral Location in.	(mm)	Original Profile Measurement in.	(mm)	Dist. Between Ref. Lines in.	(mm)	Actual in.	Crush (mm)
C_1	na	NA	-39	-(991)	29	(737)	-3 4/5	-(96)	NA	NA
C_2	10 1/4	(260)	-23 2/5	-(594)	13 1/2	(342)			4/7	(14)
C_3	6 1/2	(165)	-7 4/5	-(198)	10 1/2	(267)			- 1/5	-(5)
C_4	6 3/4	(171)	7 4/5	(198)	10 1/2	(266)			0	(1)
C_5	10	(254)	23 2/5	(594)	13 2/5	(340)			2/5	(10)
C_6	26	(660)	39	(991)	29	(737)			4/5	(20)
C_{MAX}	19 1/2	(495)	32	(813)	17 1/2	(445)			5 4/5	(147)

Figure D-17. Exterior Vehicle Crush (NASS) - Front, Test No. MWP-3

Date: 8/20/2014 **Test Number:** MWP-3

Make: Dodge Ram **Model:** 2270P **Year:** 2007



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	44 1/2	(1130)
Width of contact and induced crush - Field L:	227 1/2	(5779)
Crush measurement spacing interval (L/5) - I:	45.5	(1156)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-11.75	-(298)
Width of Contact Damage:	227 1/2	(5779)
Distance from vehicle c.g. to center of contect damage - D_C:	11 3/4	(298)

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been remeoved)

	Crush Measurement in.	Crush Measurement (mm)	Longitudinal Location in.	Longitudinal Location (mm)	Original Profile Measurement in.	Original Profile Measurement (mm)	Dist. Between Ref. Lines in.	Dist. Between Ref. Lines (mm)	Actual Crush in.	Actual Crush (mm)
C_1	na	NA	-125 1/2	-(3188)	16	(406)	-5 1/2	-(140)	NA	NA
C_2	8 1/2	(216)	-80	-(2032)	10 1/2	(267)			3 1/2	(89)
C_3	6 1/2	(165)	-34 1/2	-(876)	11 5/8	(295)			3/8	(10)
C_4	6	(152)	11	(279)	11 1/4	(286)			1/4	(6)
C_5	8	(203)	56 1/2	(1435)	10 1/2	(267)			3	(76)
C_6	na	NA	102	(2591)	35 1/4	(895)			NA	NA
C_{MAX}	10 1/4	(260)	81	(2057)	11 1/3	(287)			4 4/9	(113)

Figure D-18. Exterior Vehicle Crush (NASS) - Side, Test No. MWP-3

Appendix E. Accelerometer and Rate Transducer Data Plots, Test No. MWP-1

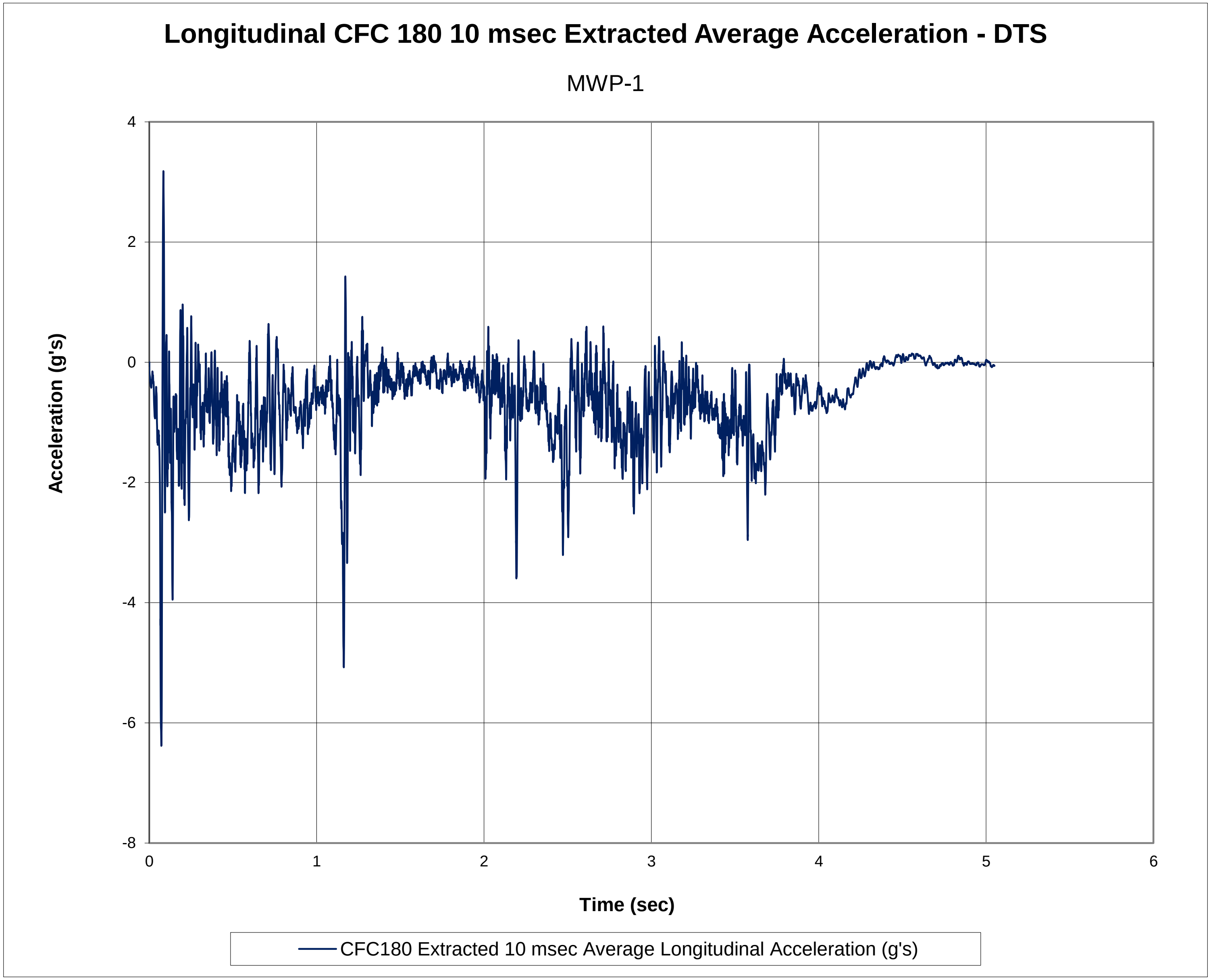


Figure E-1. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. MWP-1

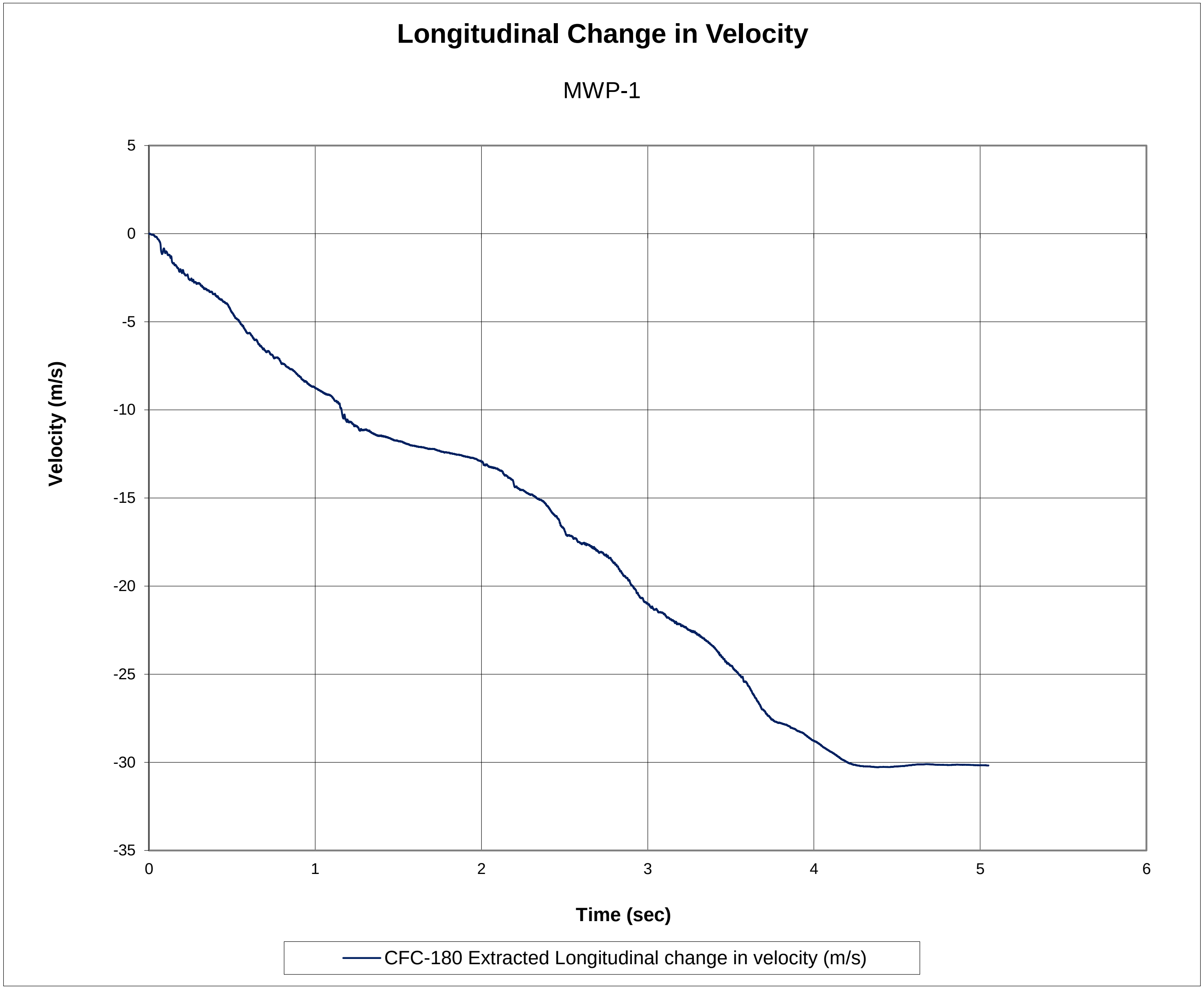


Figure E-2. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. MWP-1

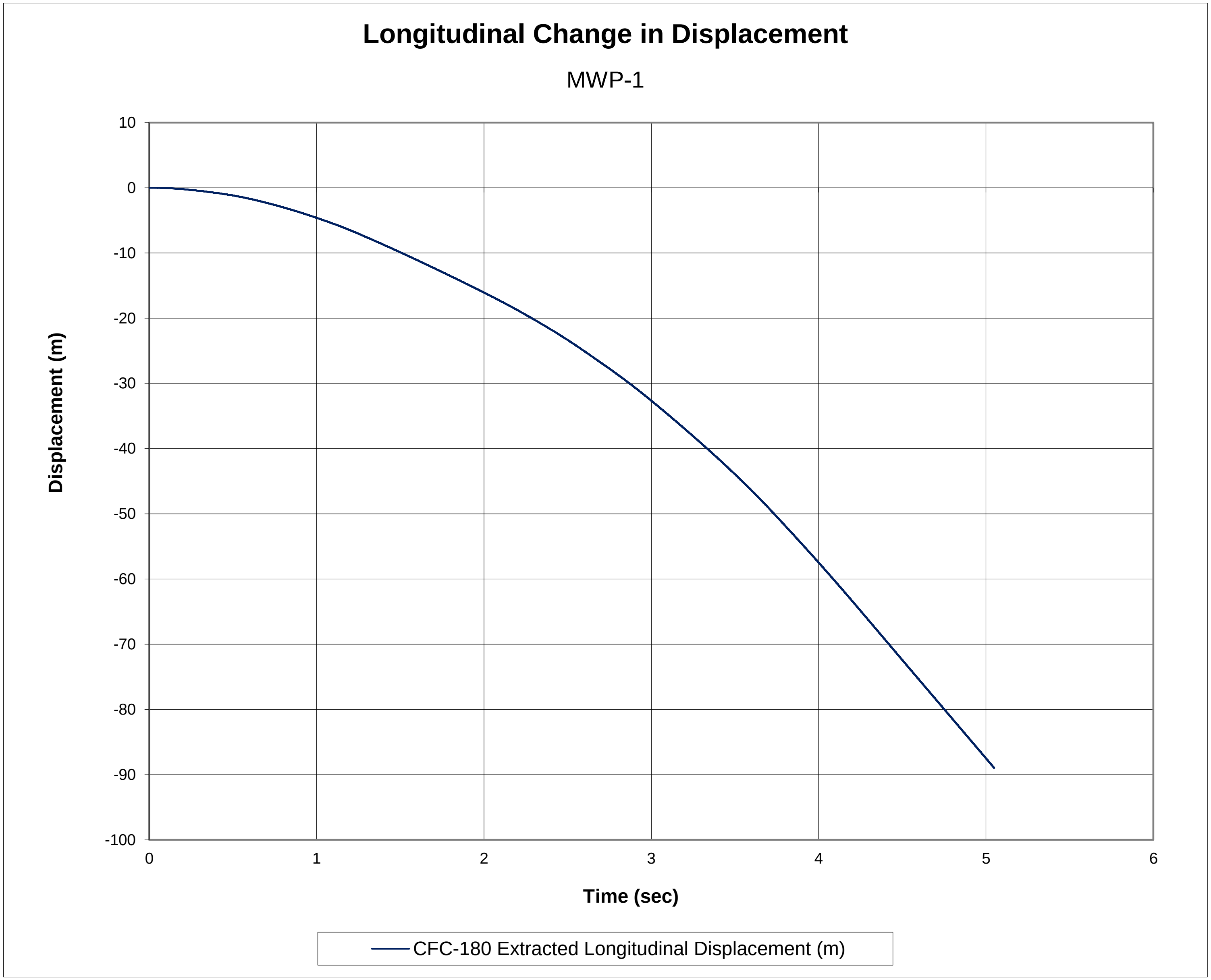


Figure E-3. Longitudinal Occupant Displacement (SLICE-2), Test No. MWP-1

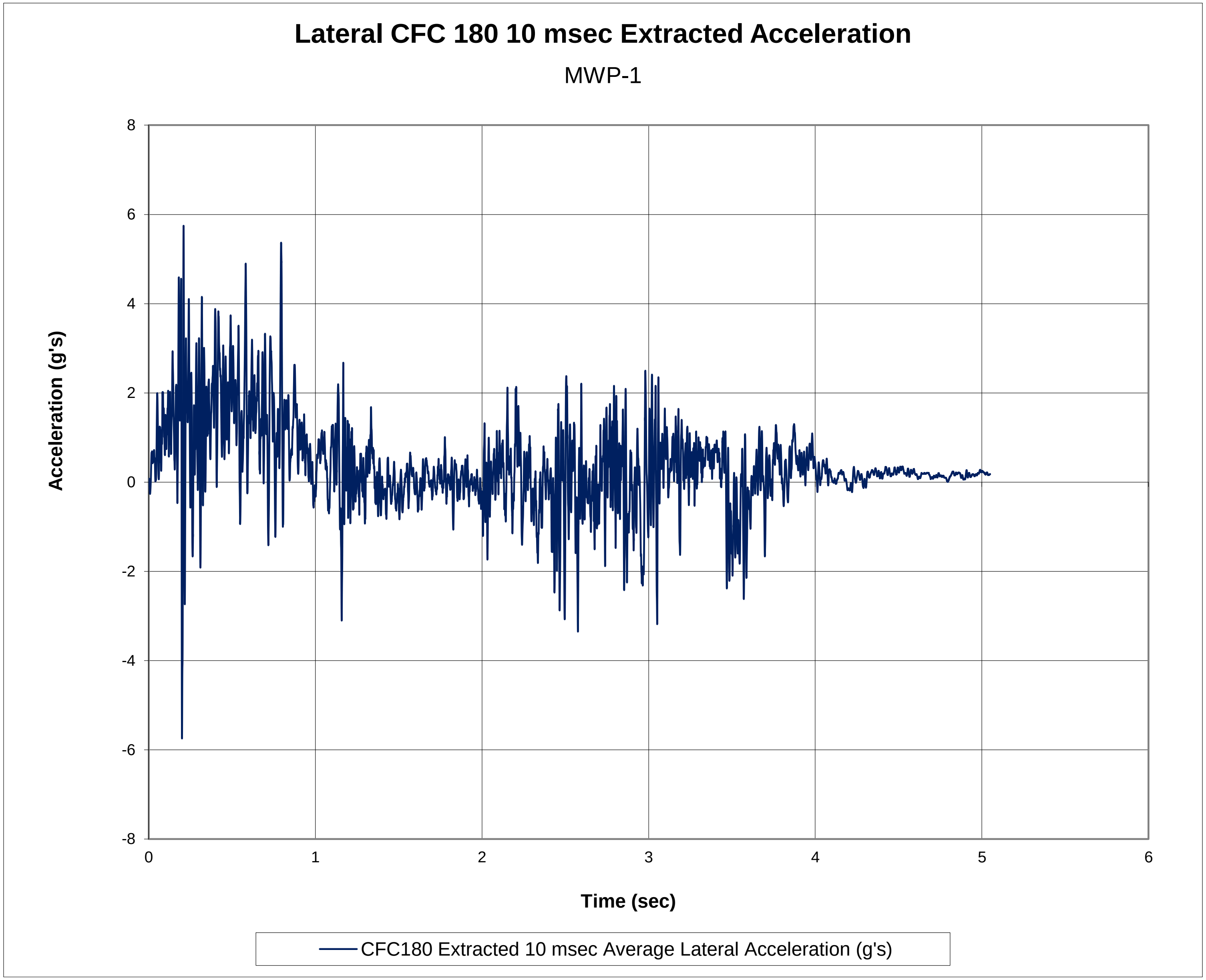


Figure E-4. 10-ms Average Lateral Deceleration (SLICE-2), Test No. MWP-1

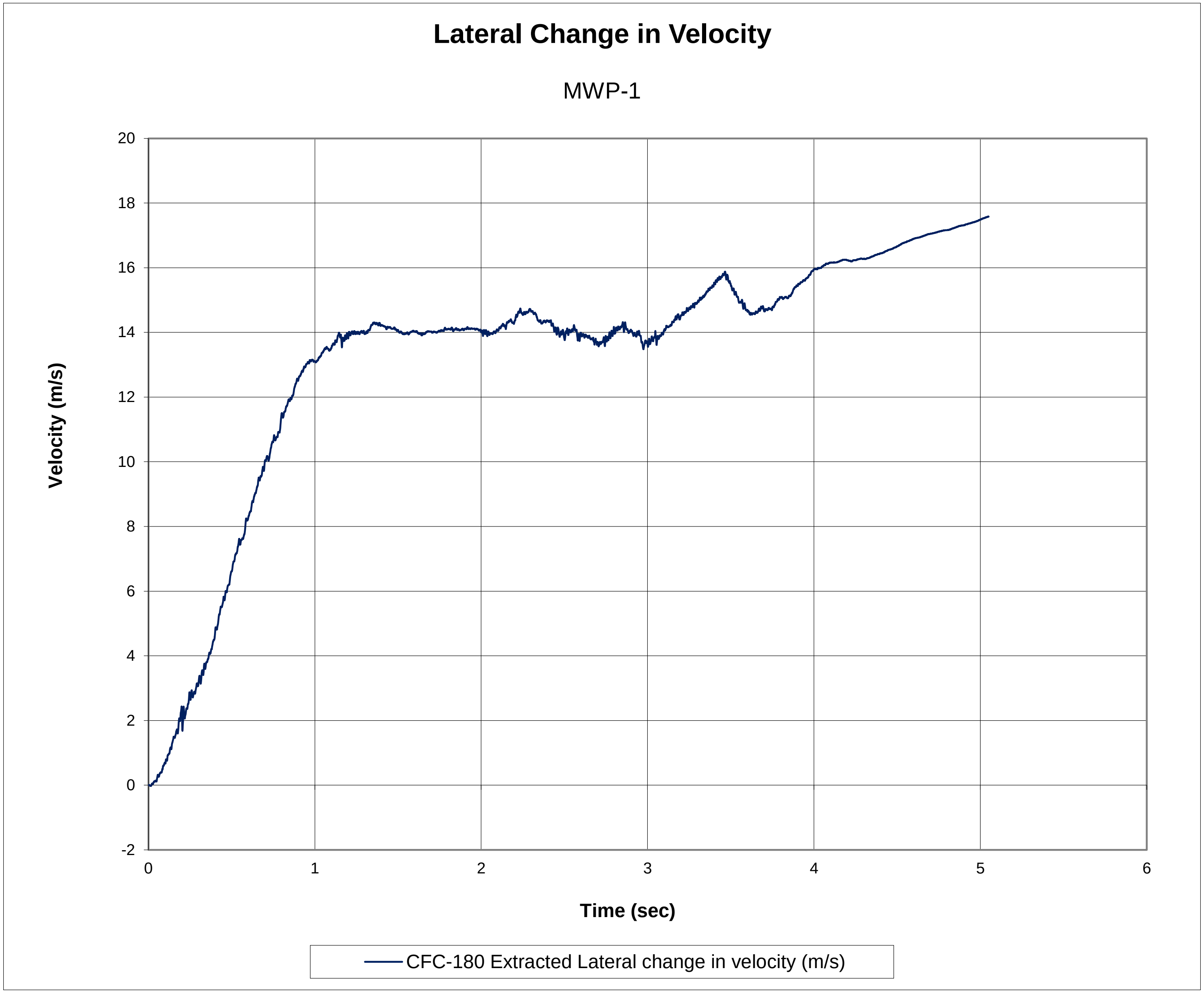


Figure E-5. Lateral Occupant Impact Velocity (SLICE-2), Test No. MWP-1

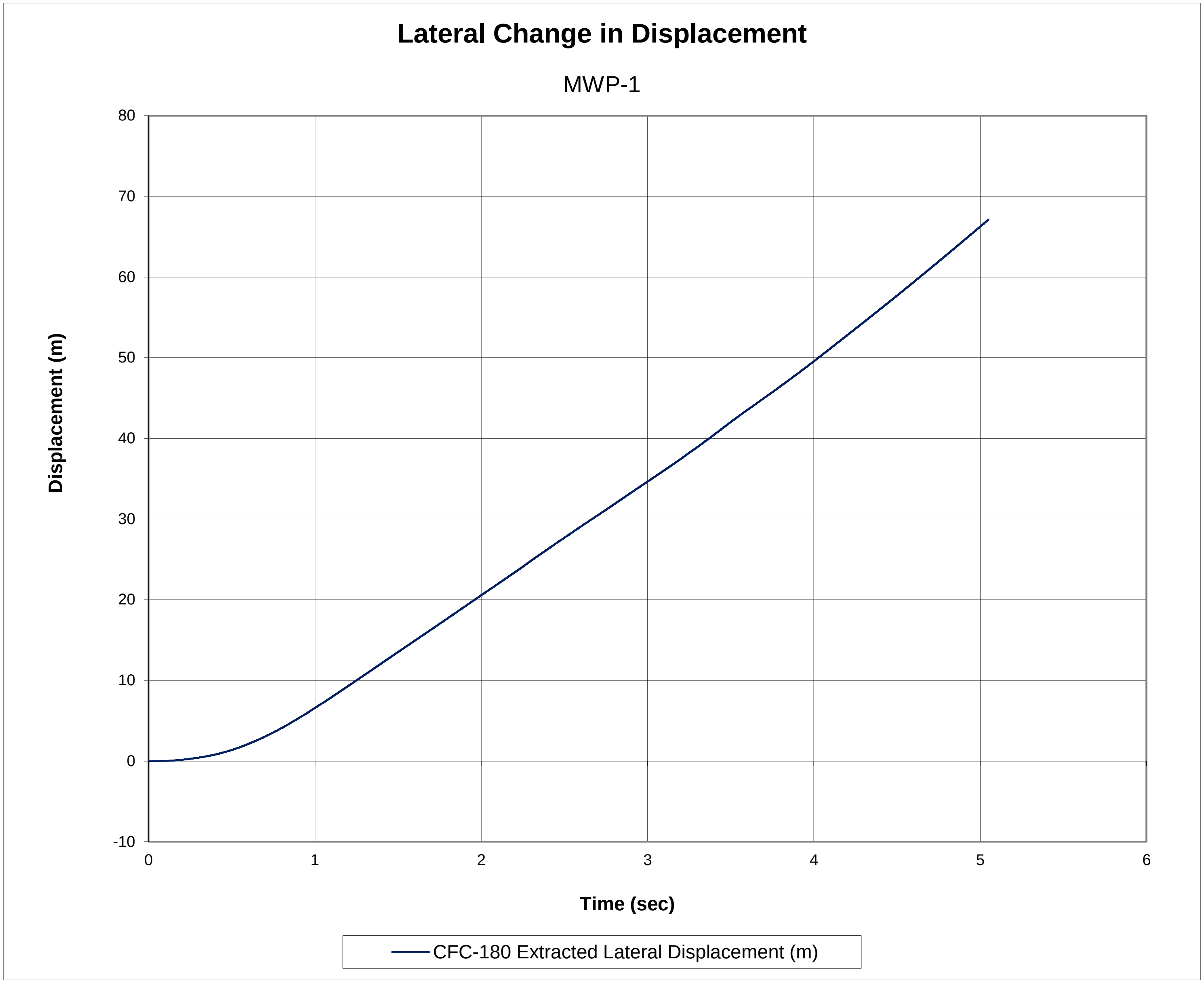


Figure E-6. Lateral Occupant Displacement (SLICE-2), Test No. MWP-1

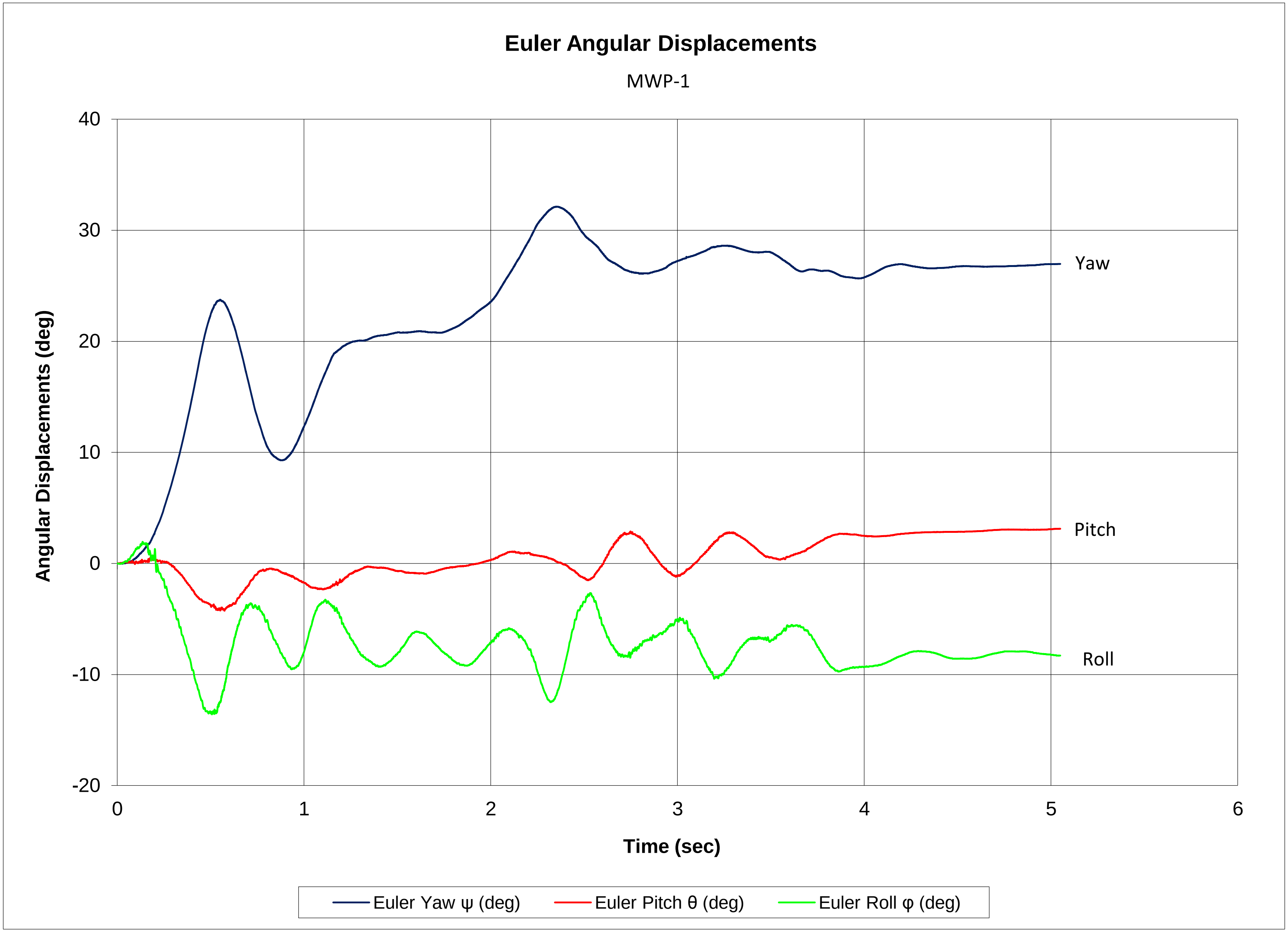


Figure E-7. Vehicle Angular Displacements (SLICE-2), Test No. MWP-1

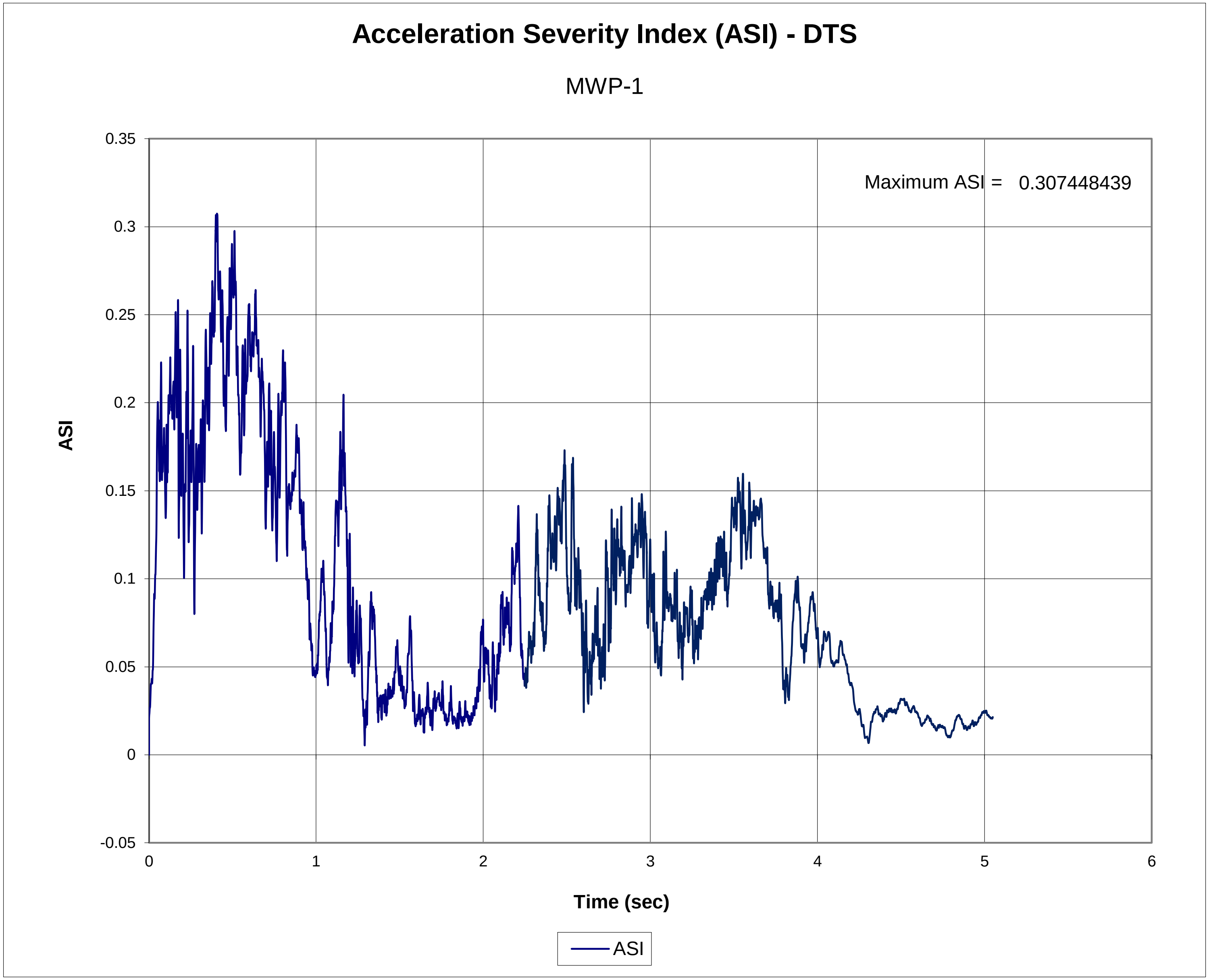


Figure E-8. Acceleration Severity Index (SLICE-2), Test No. MWP-1

Appendix F. Load Cell and String Potentiometer Data, Test No. MWP-1

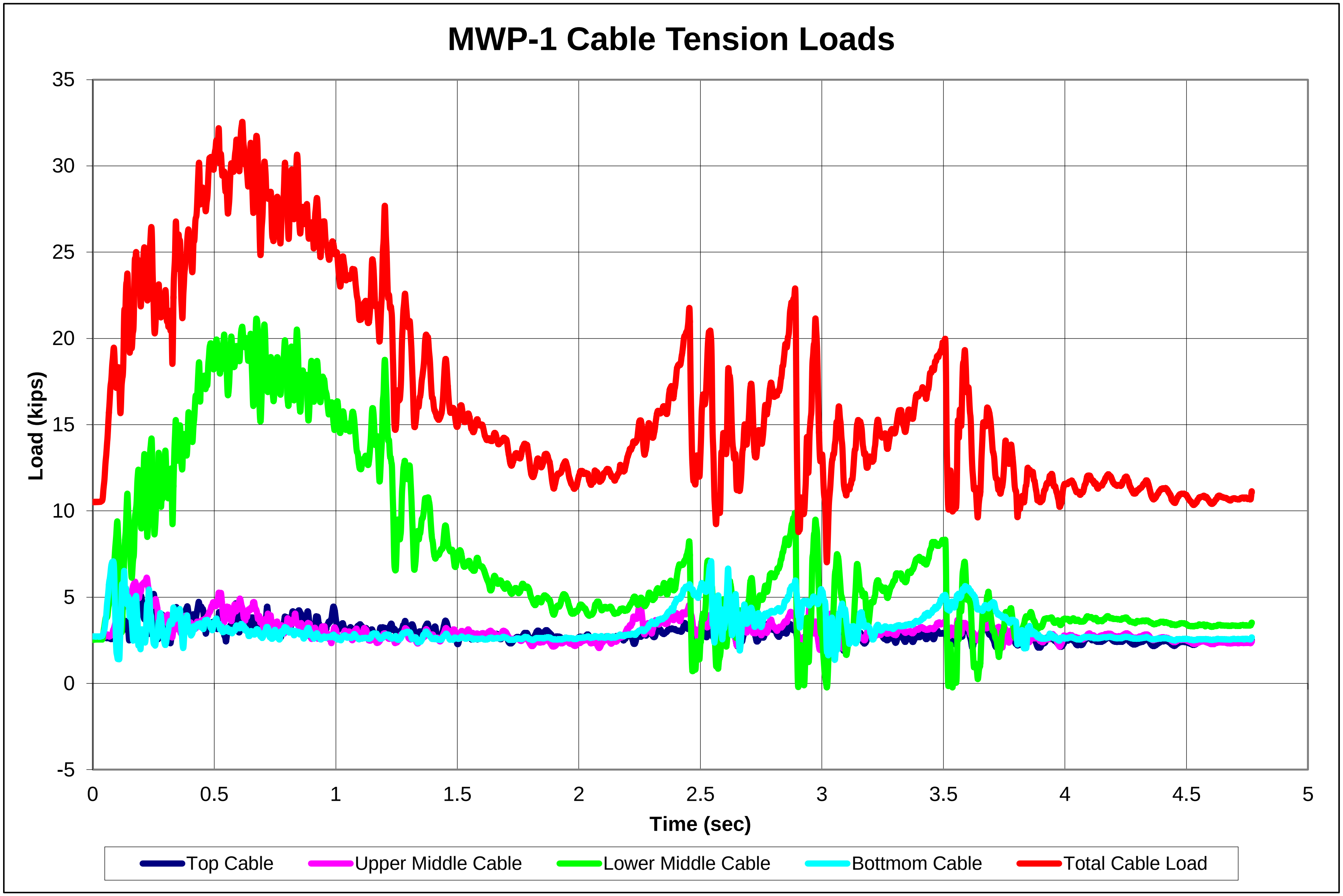


Figure F-1. Combined Load Cell Data, Test No. MWP-1

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

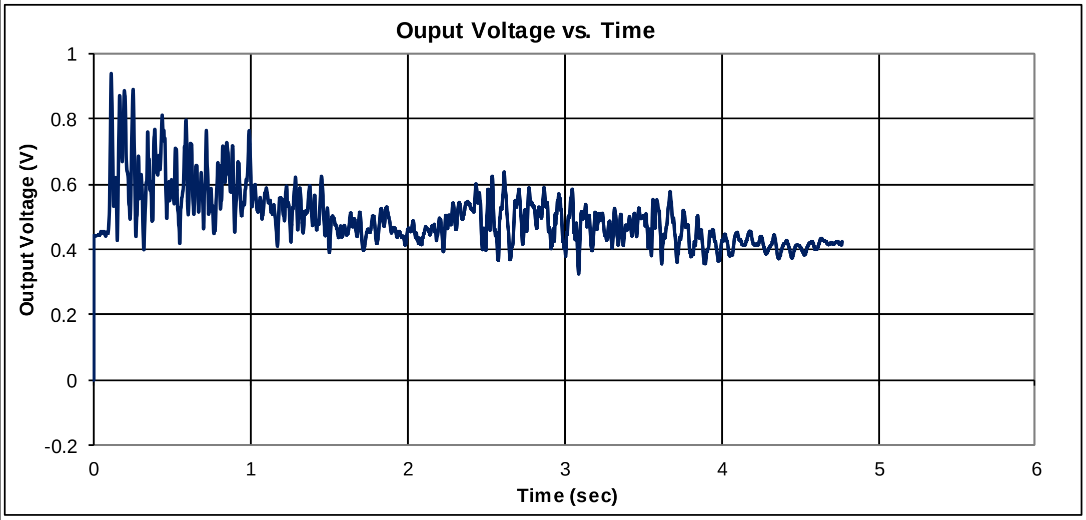
Test No:	MWP-1
Date:	3/26/2014
System / Test Article:	4 Cable Barrier - Top cable
LC Location / Component:	Between post nos. 4 and 5
Additional Notes:	Load cells were zeroed and then tensioned before the test.

Load Cell Information:

Load Cell No.:	143436
Calibration Factor:	2.14575 mv/V
Input Voltage (excitation):	10 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	5.47 kips
Time of Max. Load:	0.1114 sec
Event Duration:	4.7691 sec
Final Load:	2.47 kips



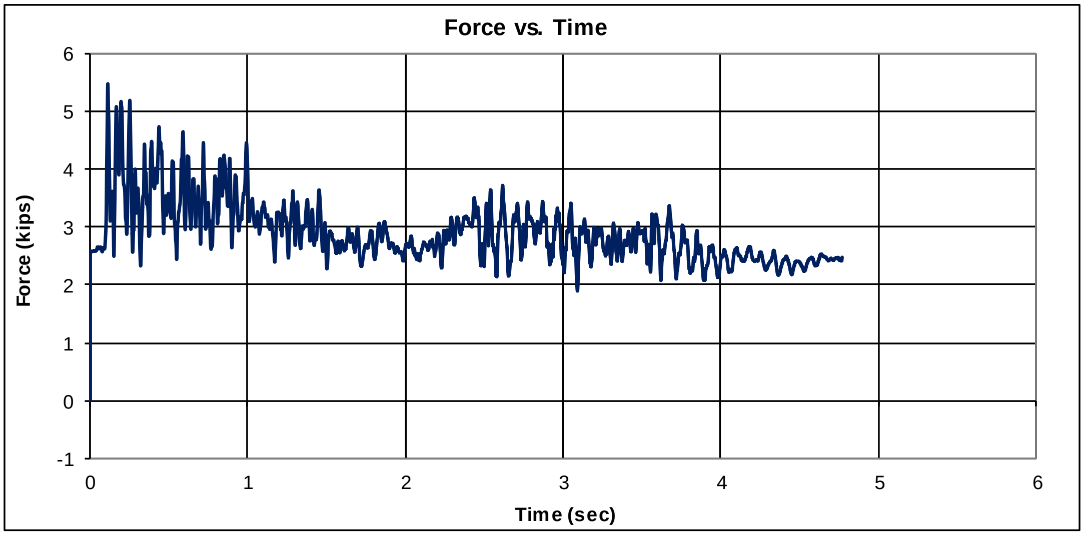


Figure F-2. Load Cell Data, Cable 4, Test No. MWP-1

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

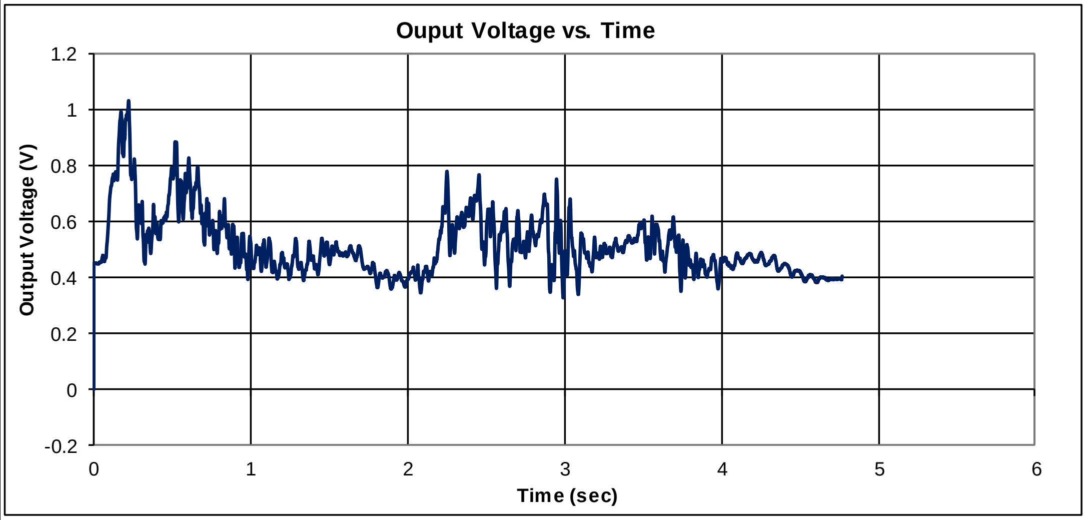
Test No:	MWP-1
Date:	3/26/2014
System / Test Article:	4 Cable Barrier - 2nd Cable from Top
LC Location / Component:	Between post nos. 4 and 5
Additional Notes:	Load cells were zeroed and then tensioned before the test.

Load Cell Information:

Load Cell No.:	143432
Calibration Factor:	2.106409 mv/V
Input Voltage (excitation):	9.99 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	6.13 kips
Time of Max. Load:	0.2223 sec
Event Duration:	4.7691 sec
Final Load:	2.41 kips



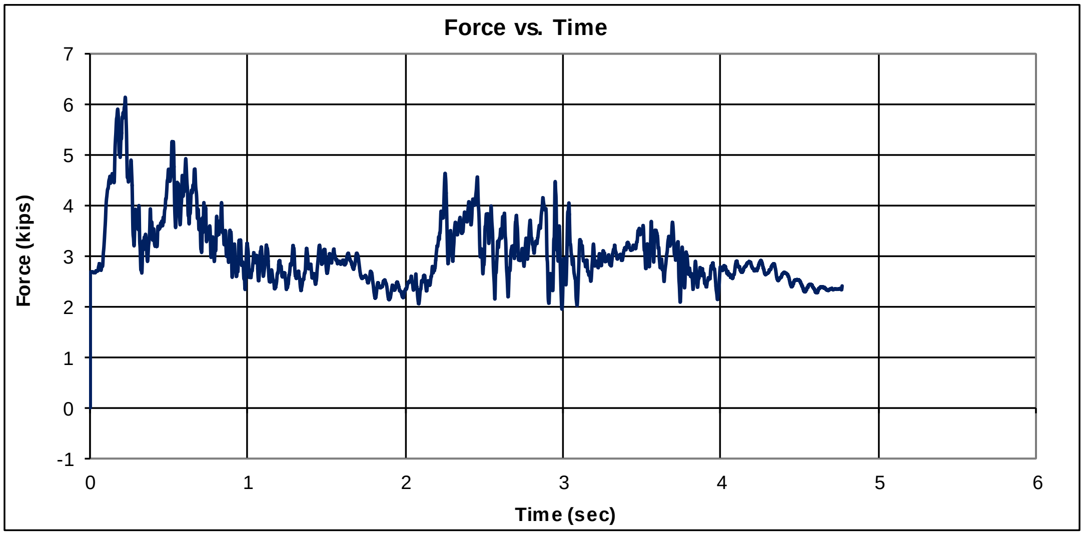


Figure F-3. Load Cell Data, Cable 3, Test No. MWP-1

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

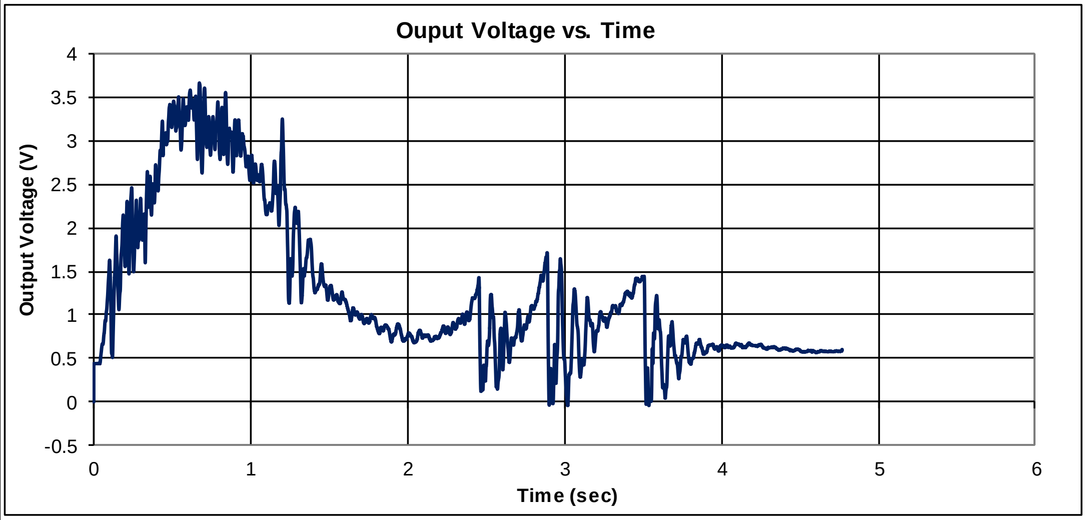
Test No: MWP-1
Date: 3/26/2014
System / Test Article: 4 Cable Barrier - 3rd Cable from Top
LC Location / Component: Between post nos. 4 and 5
Additional Notes: Load cells were zeroed and then tensioned before the test.

Load Cell Information:

Load Cell No.:	143433
Calibration Factor:	2.16517 mv/V
Input Voltage (excitation):	10 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	21.15 kips
Time of Max. Load:	0.6732 sec
Event Duration:	4.7691 sec
Final Load:	3.48 kips



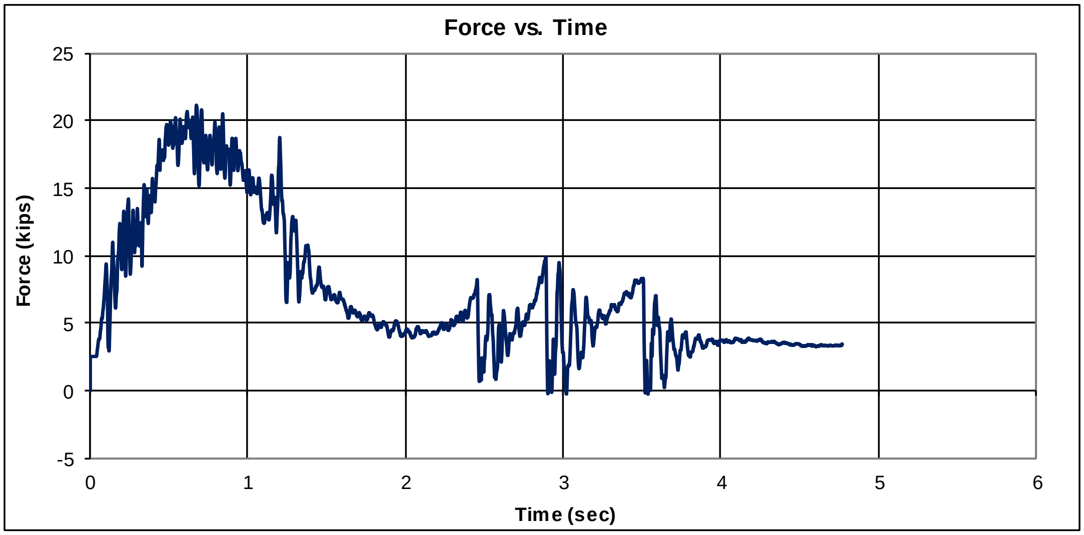


Figure F-4. Load Cell Data, Cable 2, Test No. MWP-1

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

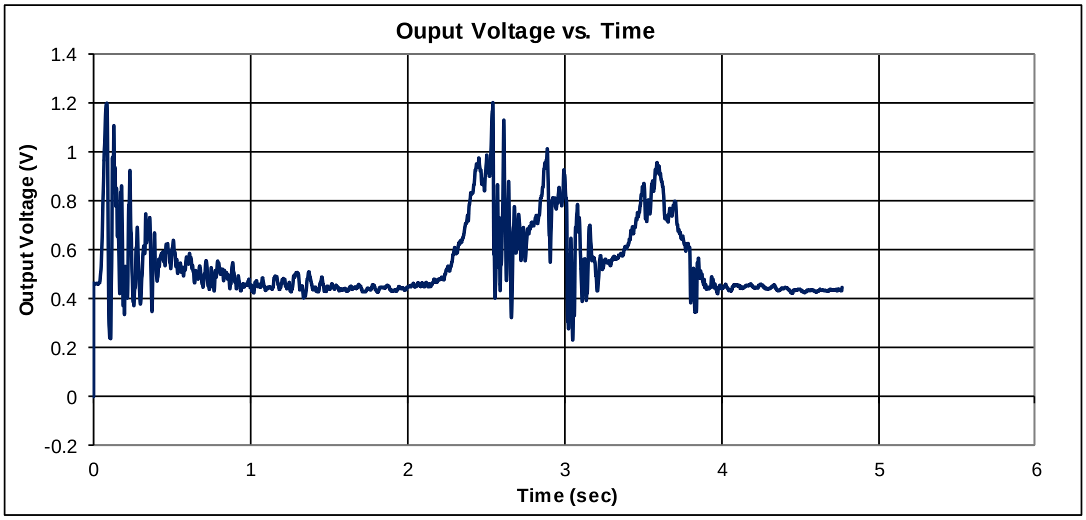
Test No:	MWP-1
Date:	3/26/2014
System / Test Article:	4 Cable Barrier - Bottom Cable
LC Location / Component:	Between post nos. 4 and 5
Additional Notes:	Load cells were zeroed and then tensioned before the test.

Load Cell Information:

Load Cell No.:	120642
Calibration Factor:	2.12022 mv/V
Input Voltage (excitation):	10 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	7.08 kips
Time of Max. Load:	2.5443 sec
Event Duration:	4.7691 sec
Final Load:	2.63 kips



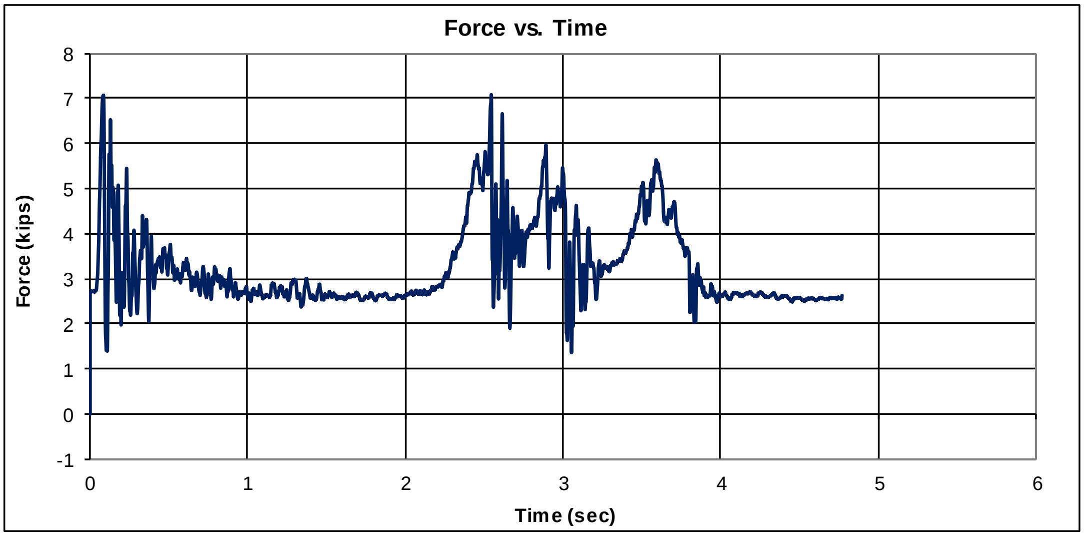


Figure F-5. Load Cell Data, Cable 1, Test No. MWP-1

MIDWEST ROADSIDE SAFETY FACILITY

String Potentiometer Summary

Test Information:

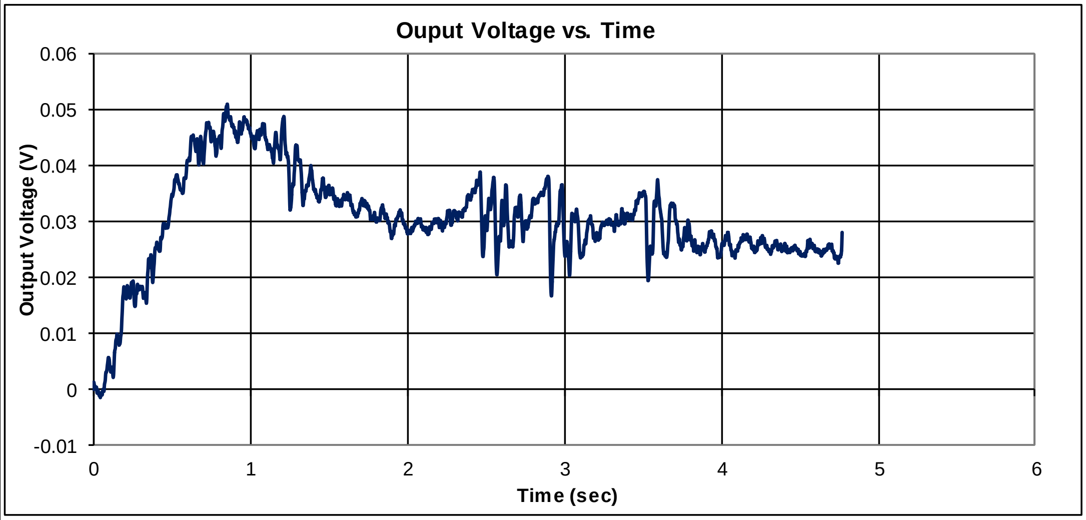
Test No:	MWP-1
Date:	3/26/2014
System / Test Article:	4 Cable Barrier
SP Location / Component:	Upstream End Anchorage
Additional Notes:	NA

String Potentiometer Information:

String Pot No.:	27039202
Calibration Factor:	19.4483 mV/V/in.
Input Voltage (excitation):	10.01 Volts
Gain:	1
Full Scale Load:	1
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Max. Displacement:	0.26 in.
Time of Max. Displacement:	0.851 sec
Event Duration:	4.7691 sec
Final Displacement:	0.14 in.



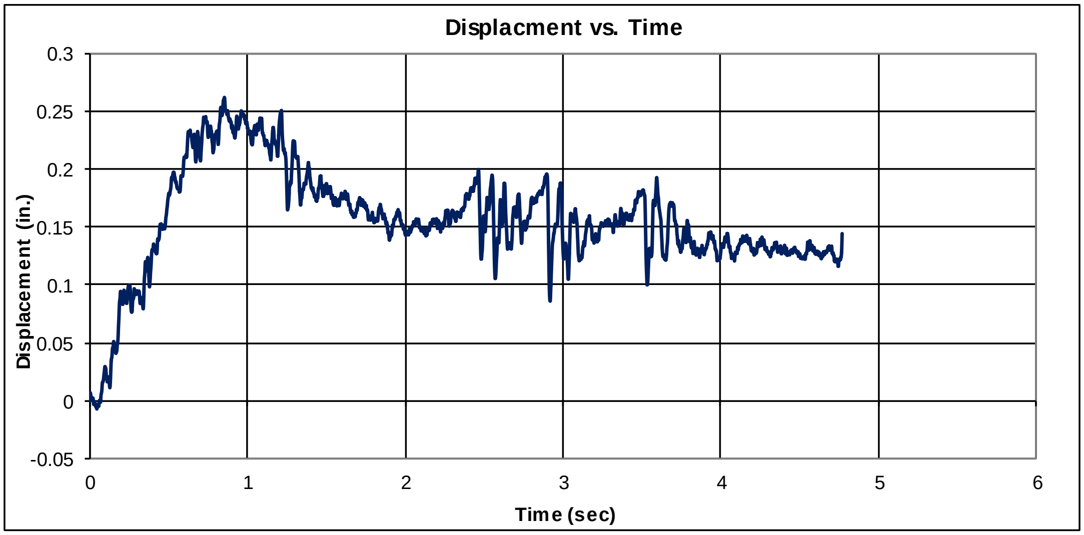


Figure F-6. String Potentiometer Data, Test No. MWP-1

Appendix G. Accelerometer and Rate Transducer Data Plots, Test No. MWP-2

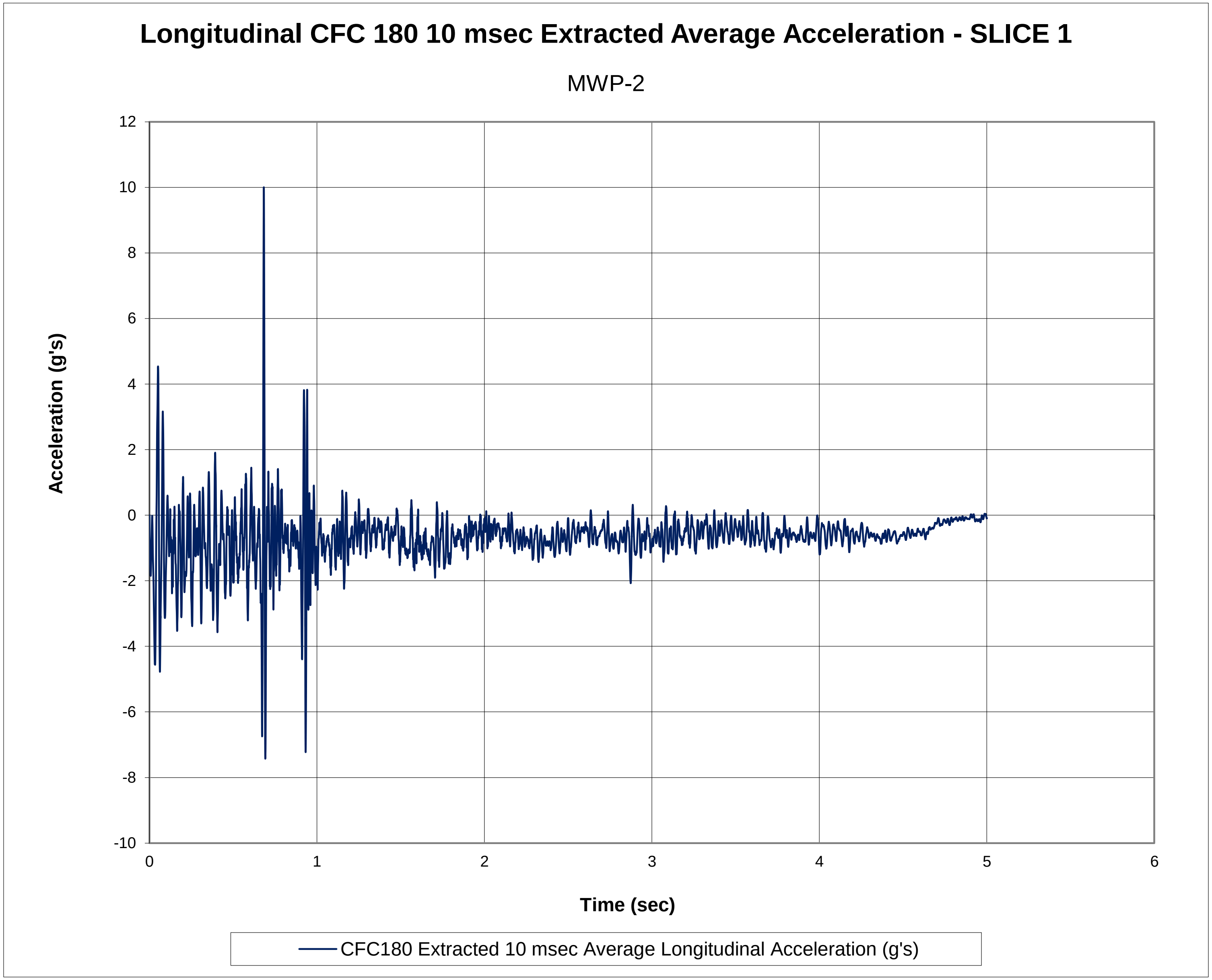


Figure G-1. 10-ms Average Longitudinal Deceleration (SLICE 1), Test No. MWP-2

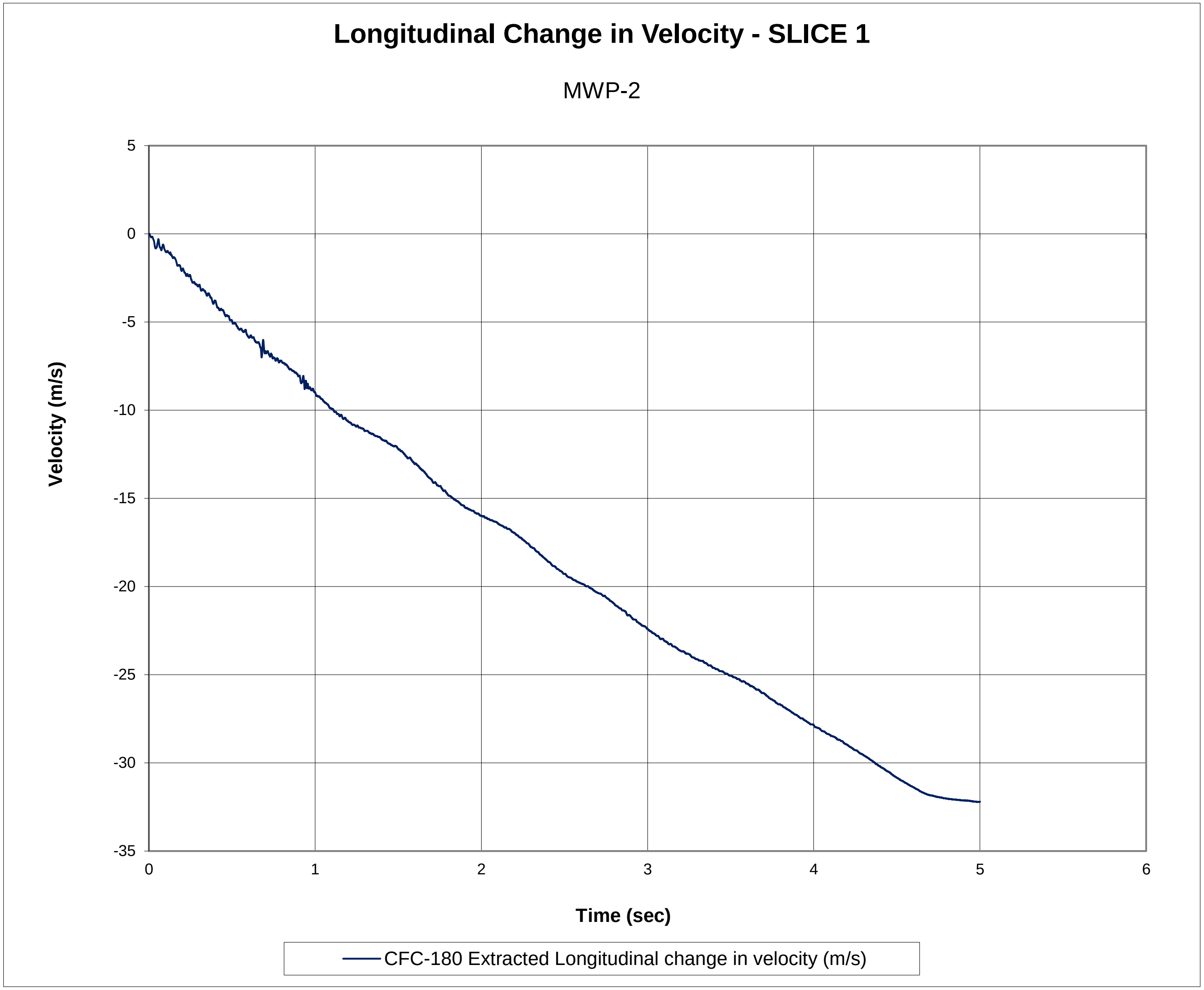


Figure G-2. Longitudinal Occupant Impact Velocity (SLICE 1), Test No. MWP-2

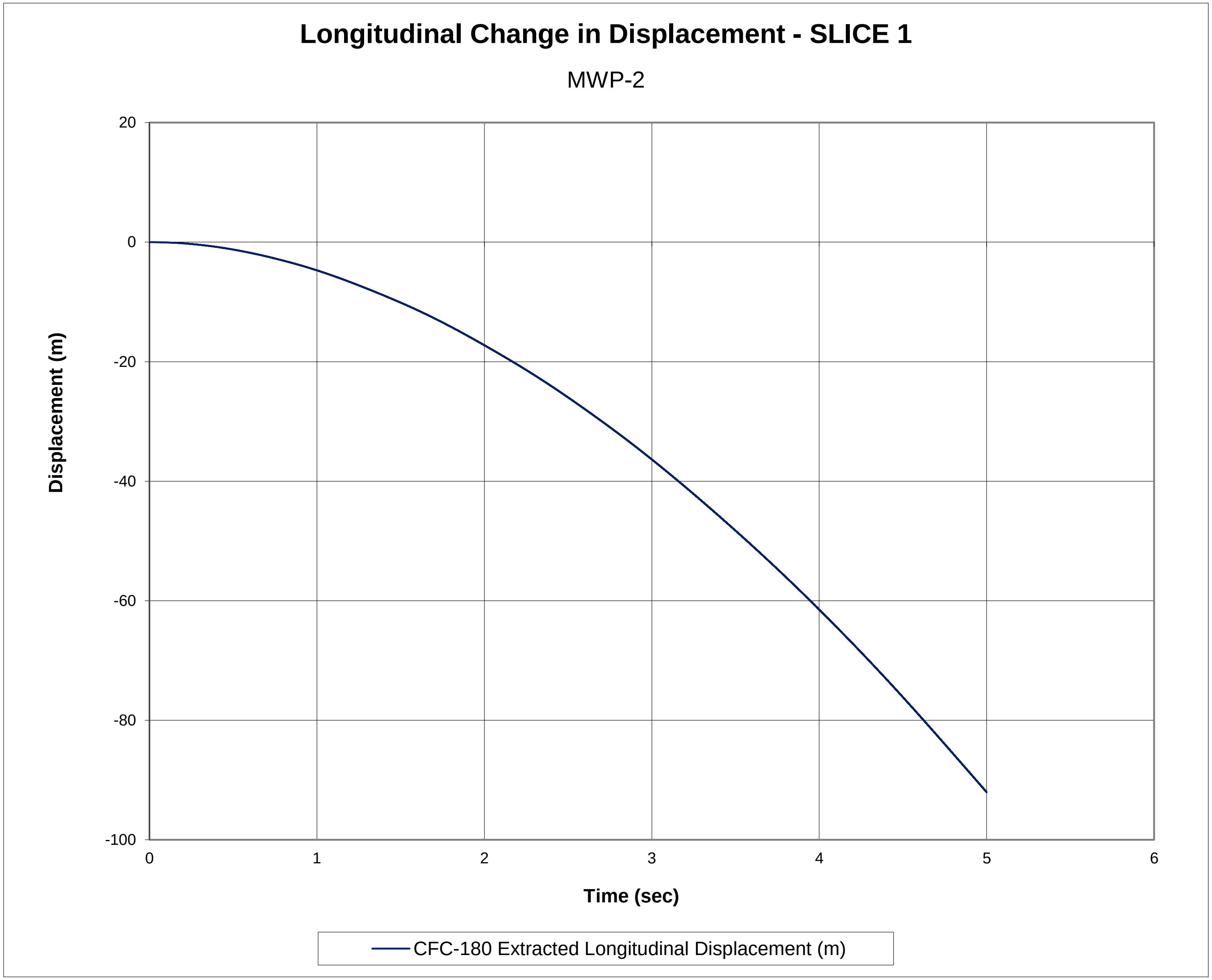


Figure G-3. Longitudinal Occupant Displacement (SLICE 1), Test No. MWP-2

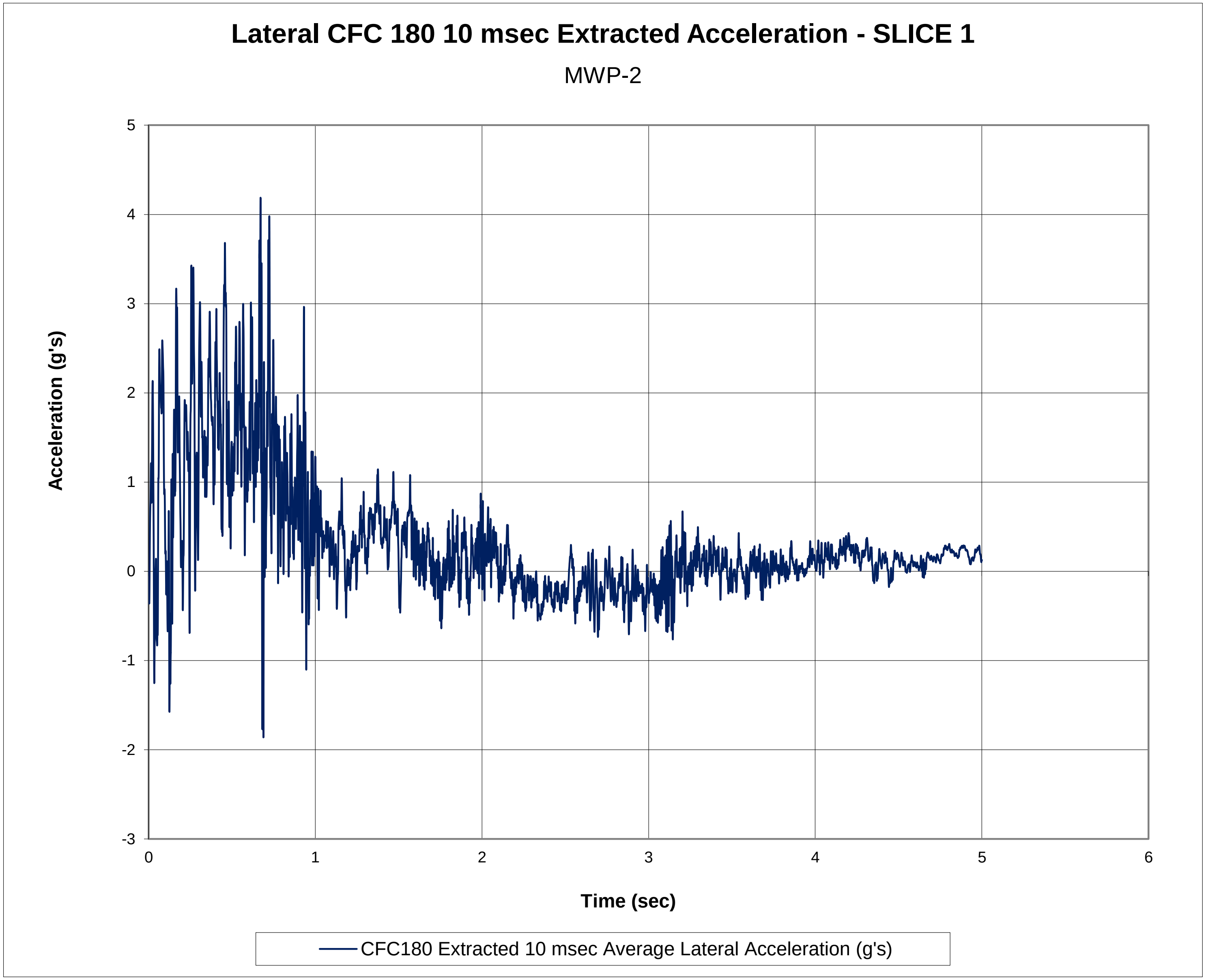


Figure G-4. 10-ms Average Lateral Deceleration (SLICE 1), Test No. MWP-2

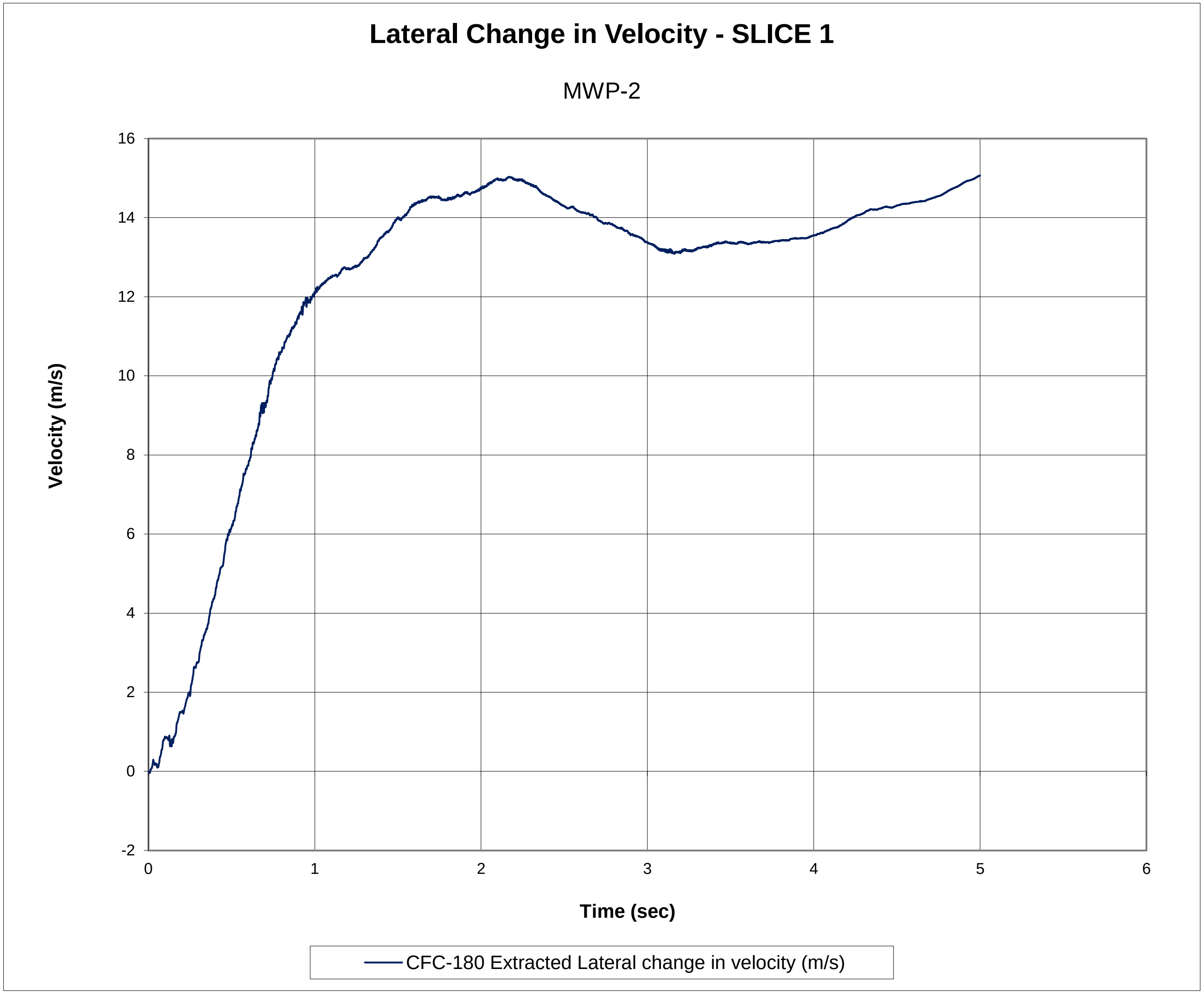


Figure G-5. Lateral Occupant Impact Velocity (SLICE 1), Test No. MWP-2

Figure G-6. Lateral Occupant Displacement (SLICE 1), Test No. MWP-2

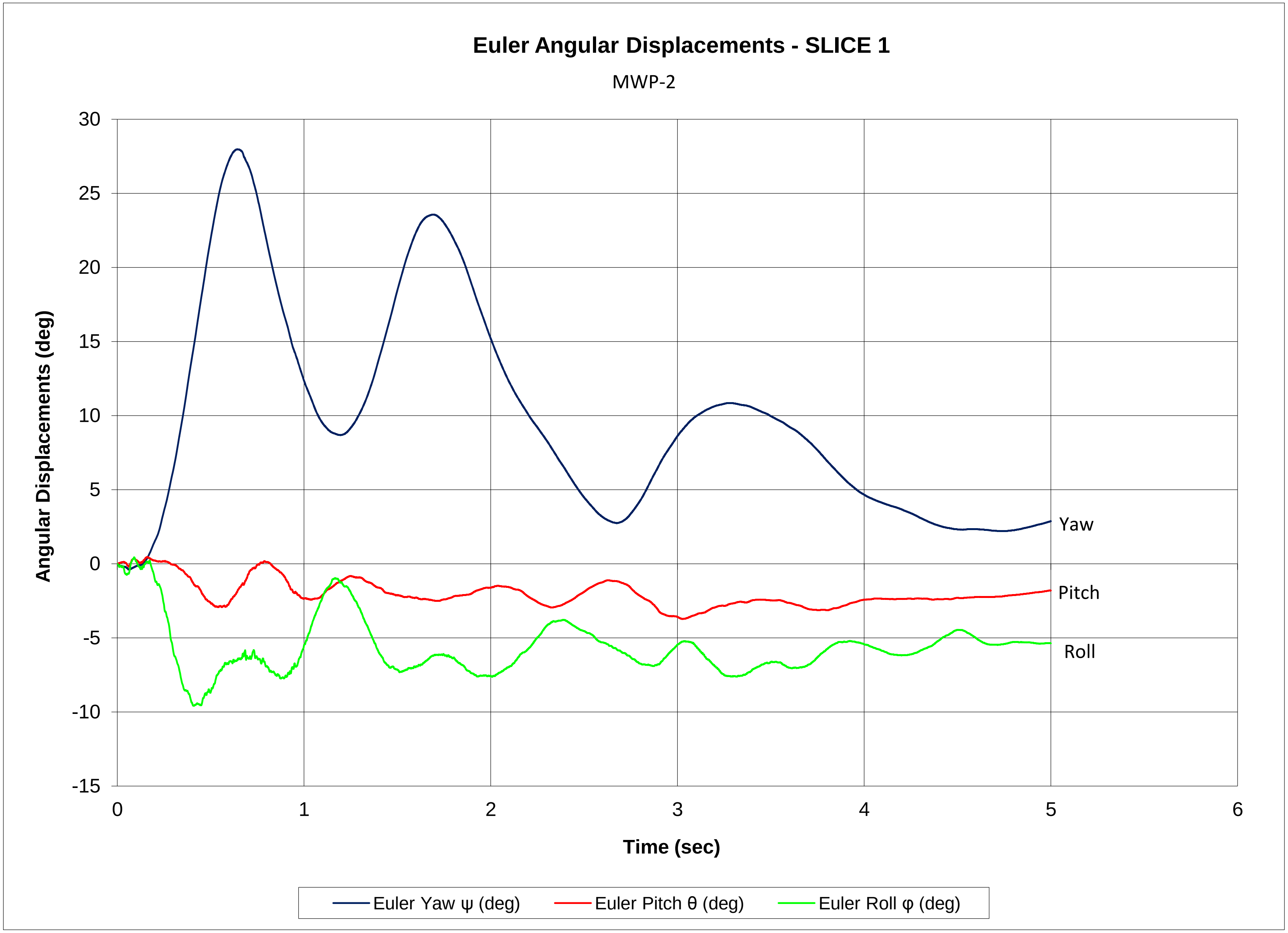


Figure G-7. Vehicle Angular Displacements (SLICE 1), Test No. MWP-2

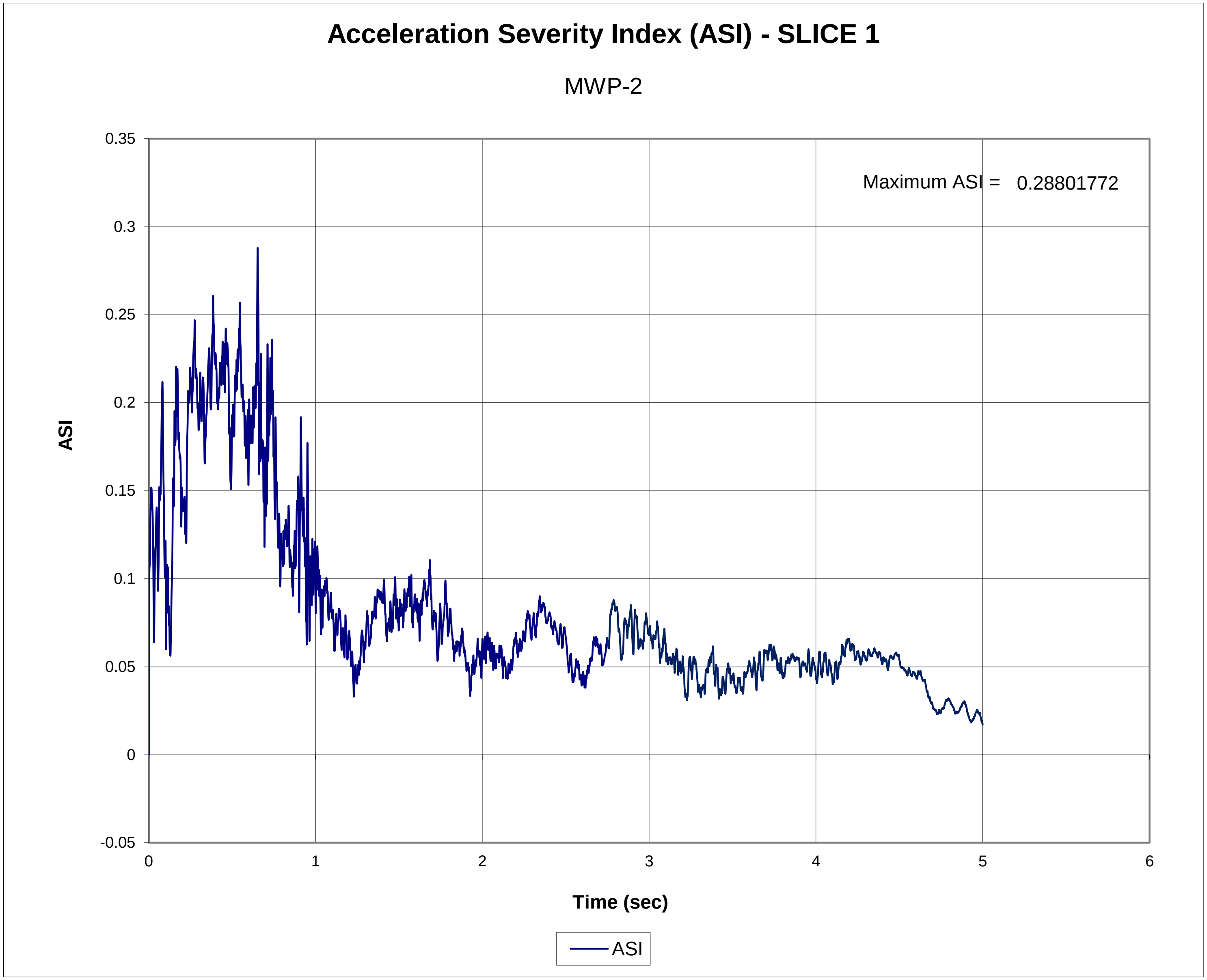


Figure G-8. Acceleration Severity Index (SLICE 1), Test No. MWP-2

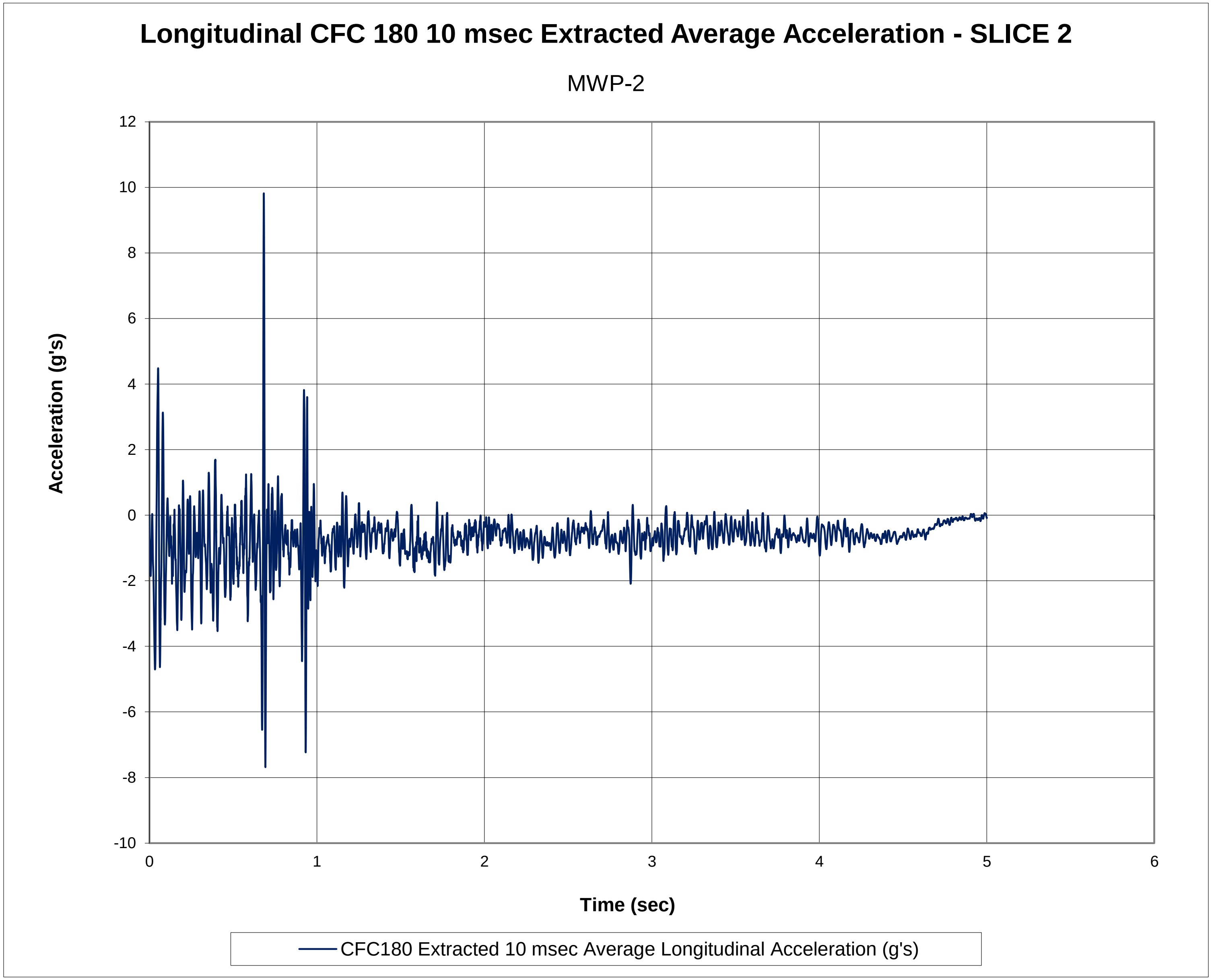


Figure G-9. 10-ms Average Longitudinal Deceleration (SLICE 2), Test No. MWP-2

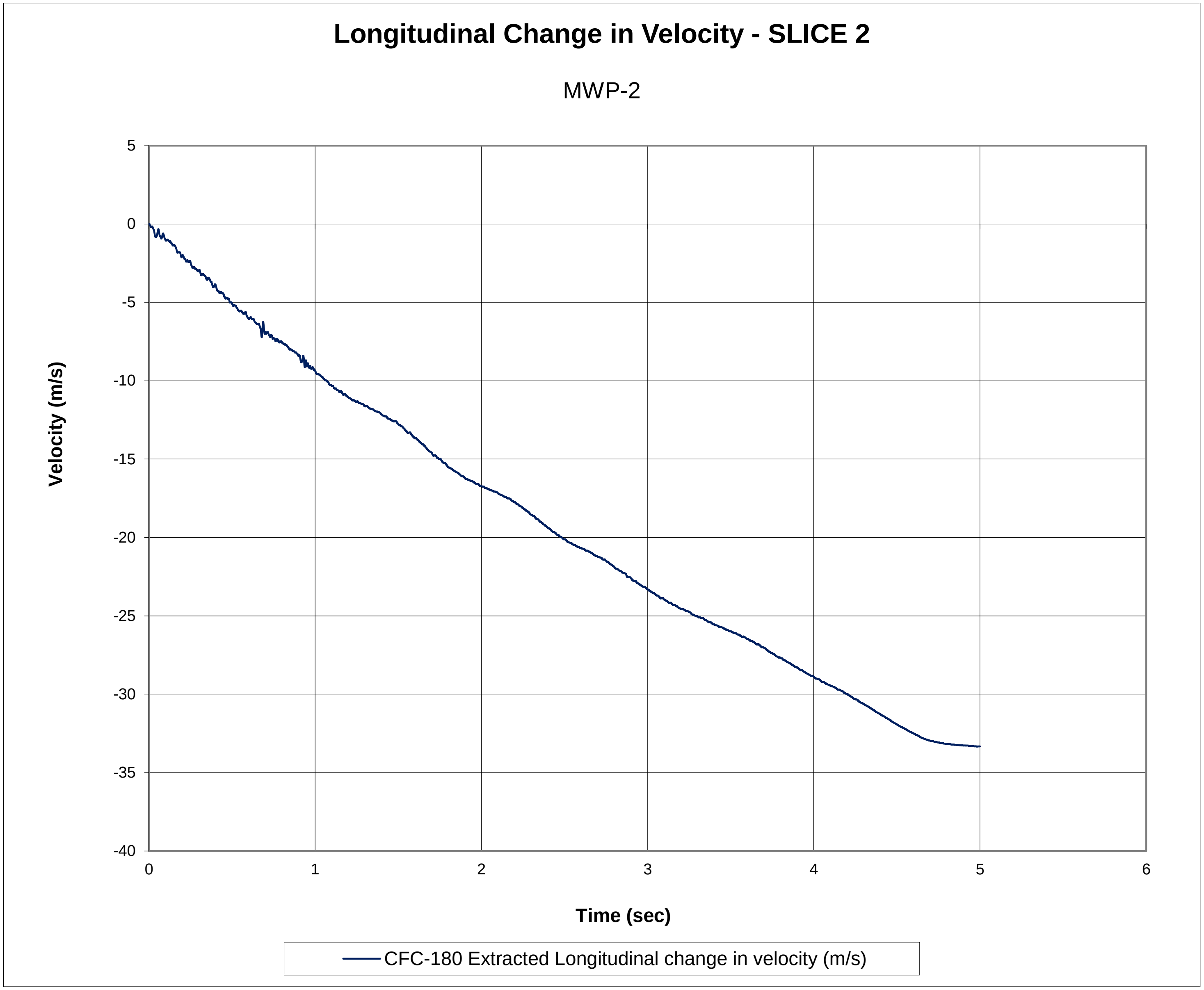


Figure G-10. Longitudinal Occupant Impact Velocity (SLICE 2), Test No. MWP-2

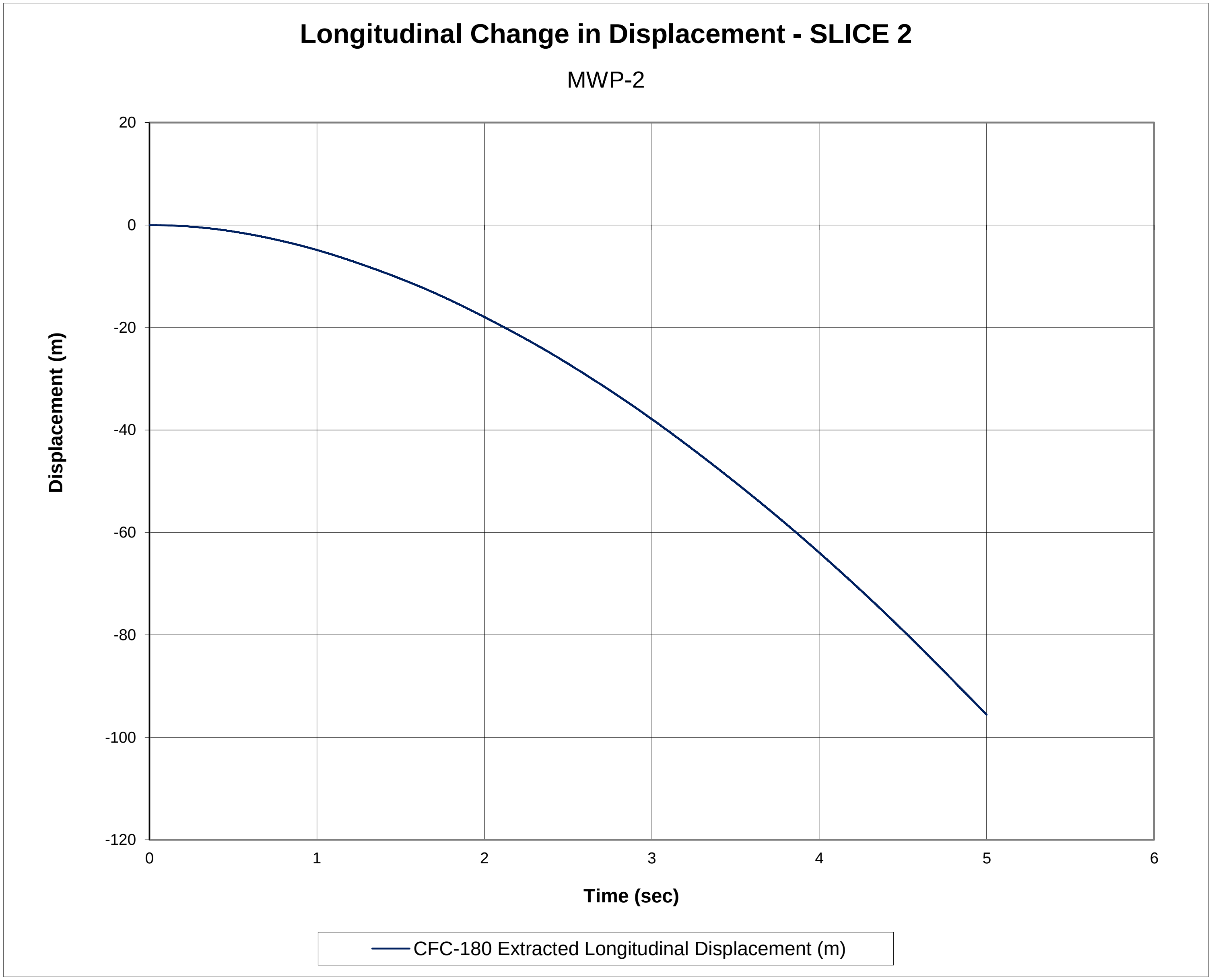


Figure G-11. Longitudinal Occupant Displacement (SLICE 2), Test No. MWP-2

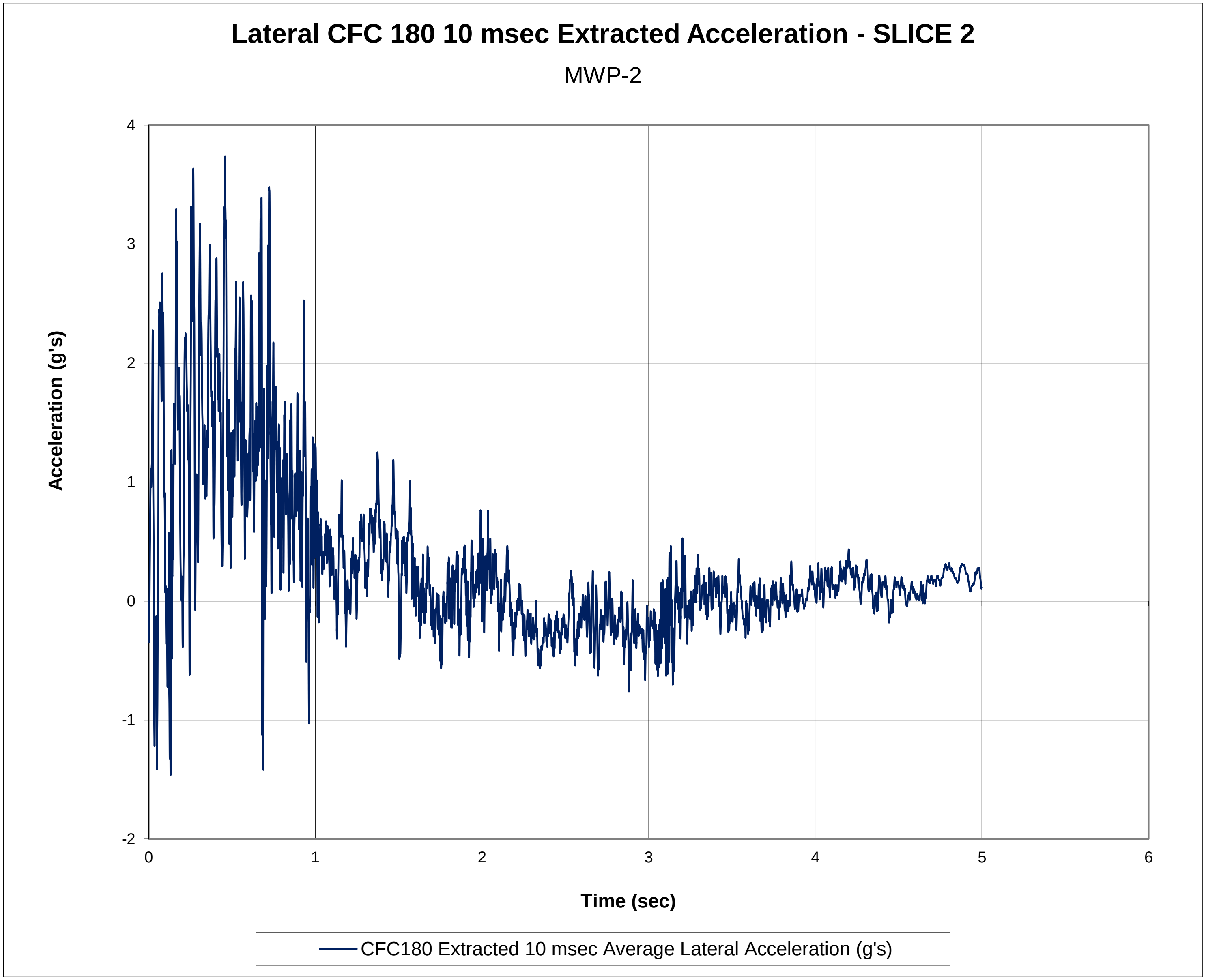


Figure G-12. 10-ms Average Lateral Deceleration (SLICE 2), Test No. MWP-2

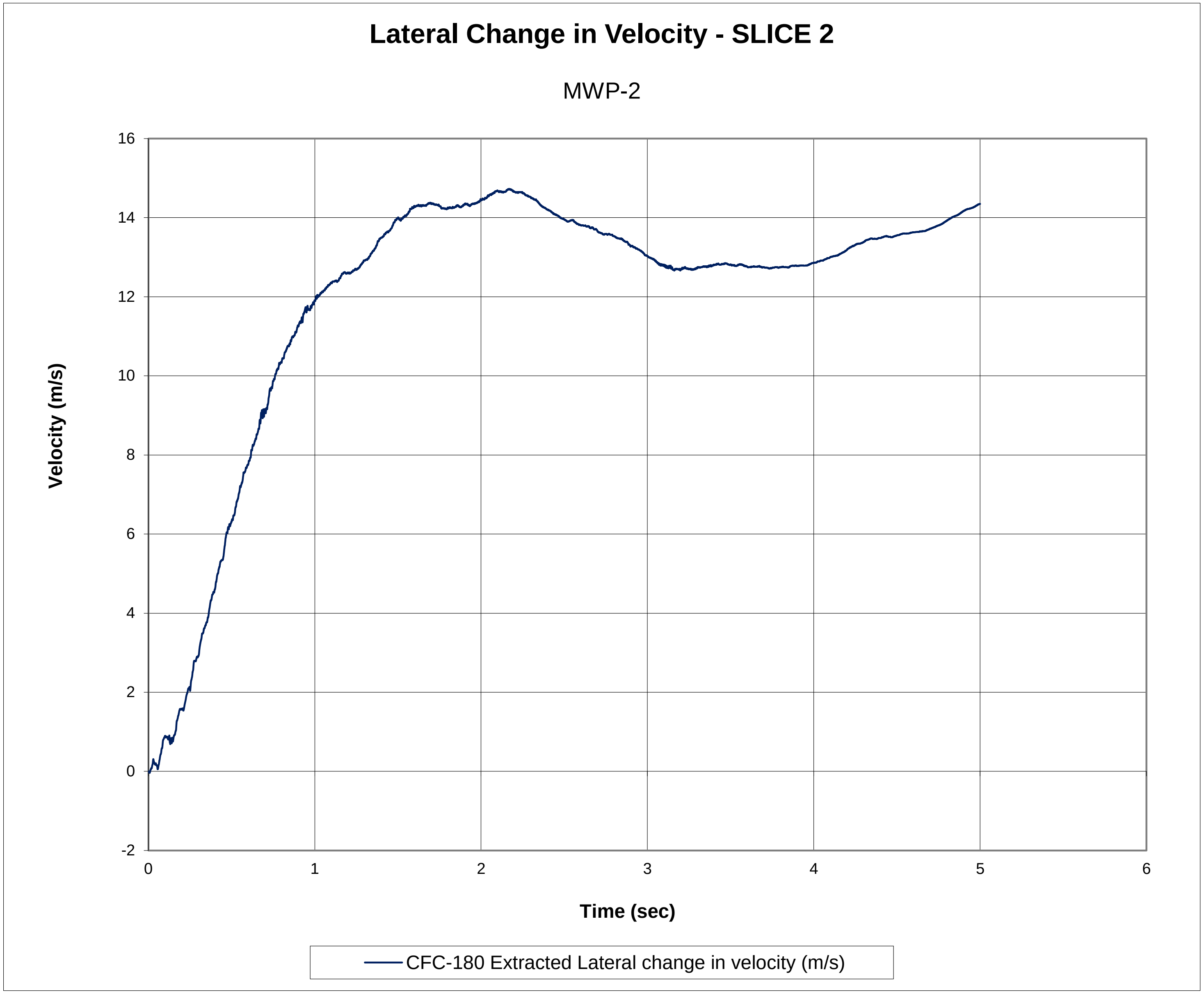


Figure G-13. Lateral Occupant Impact Velocity (SLICE 2), Test No. MWP-2

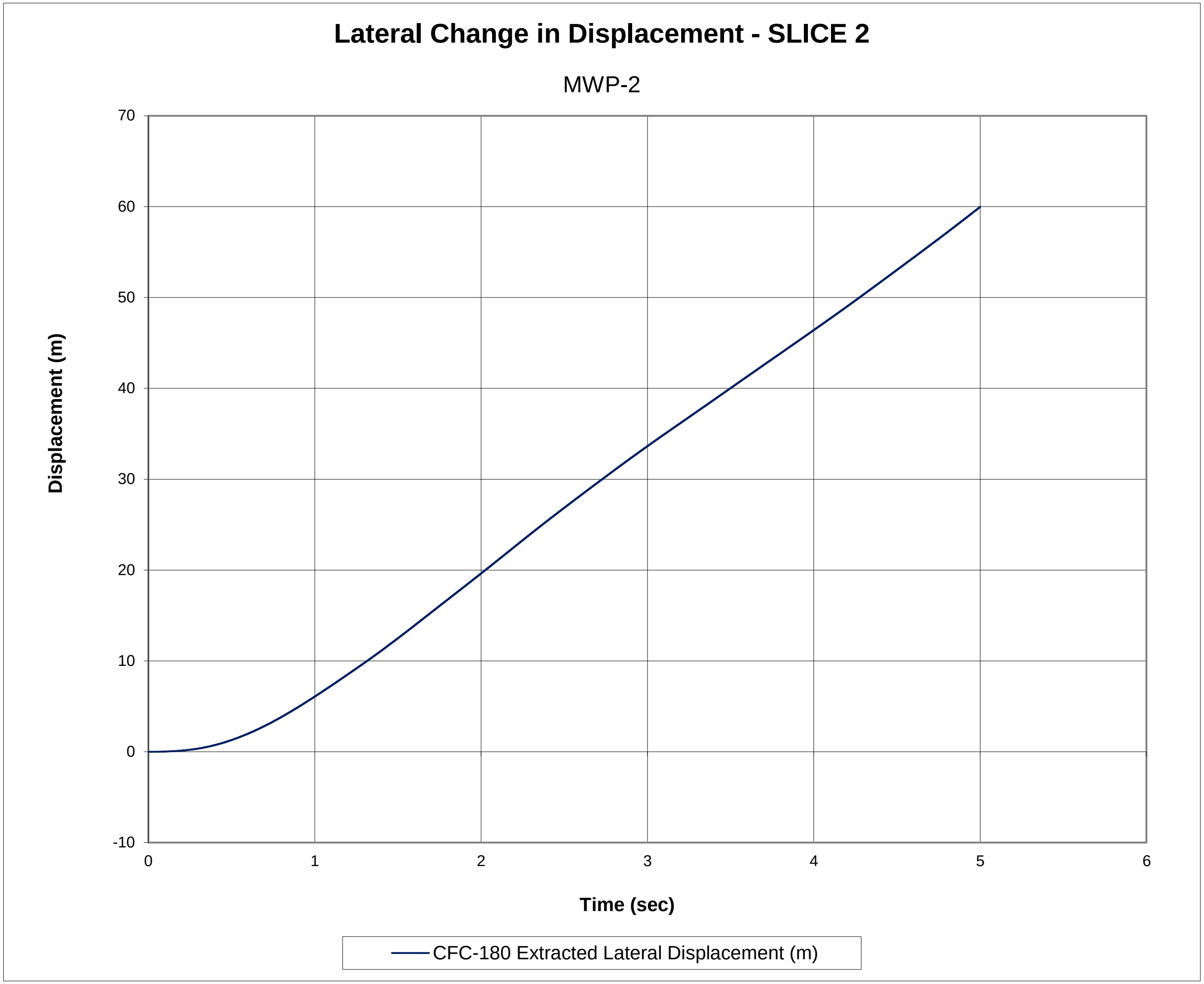


Figure G-14. Lateral Occupant Displacement (SLICE 2), Test No. MWP-2

Figure G-15. Vehicle Angular Displacements (SLICE 2), Test No. MWP-2

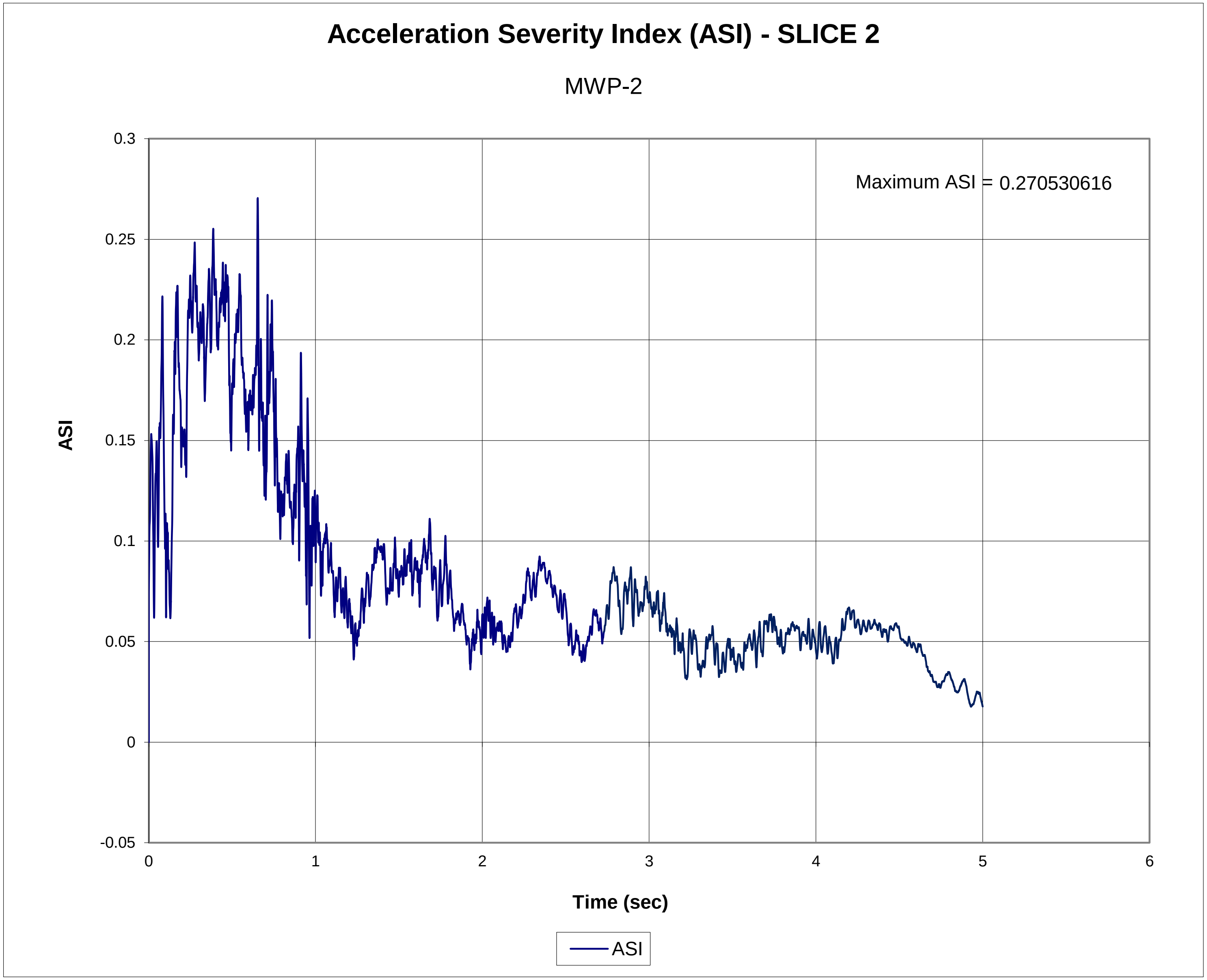


Figure G-16. Acceleration Severity Index (SLICE 2), Test No. MWP-2

Appendix H. Load Cell and String Potentiometer Data, Test No. MWP-2

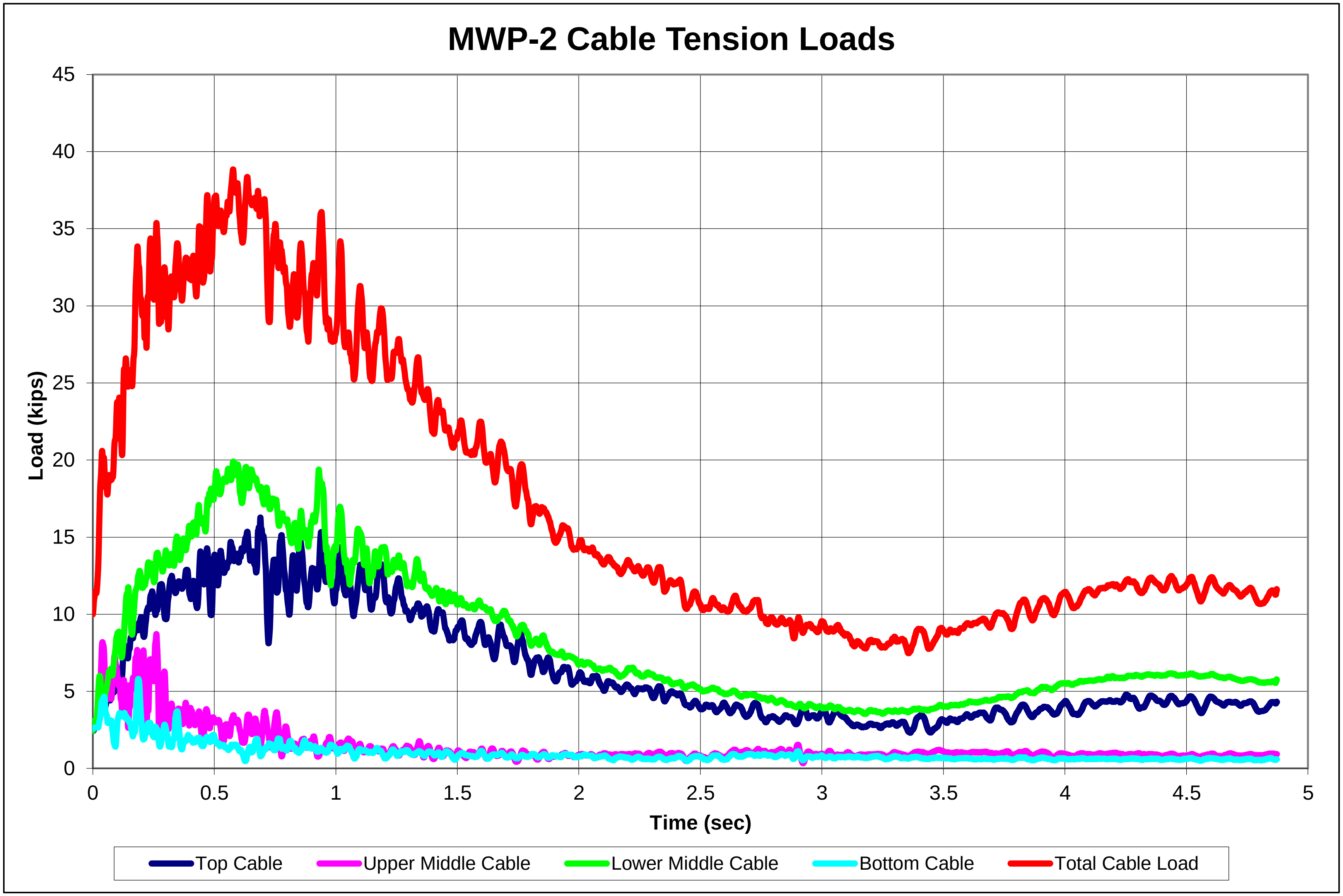


Figure H-1. Combined Load Cell Data, Test No. MWP-2

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

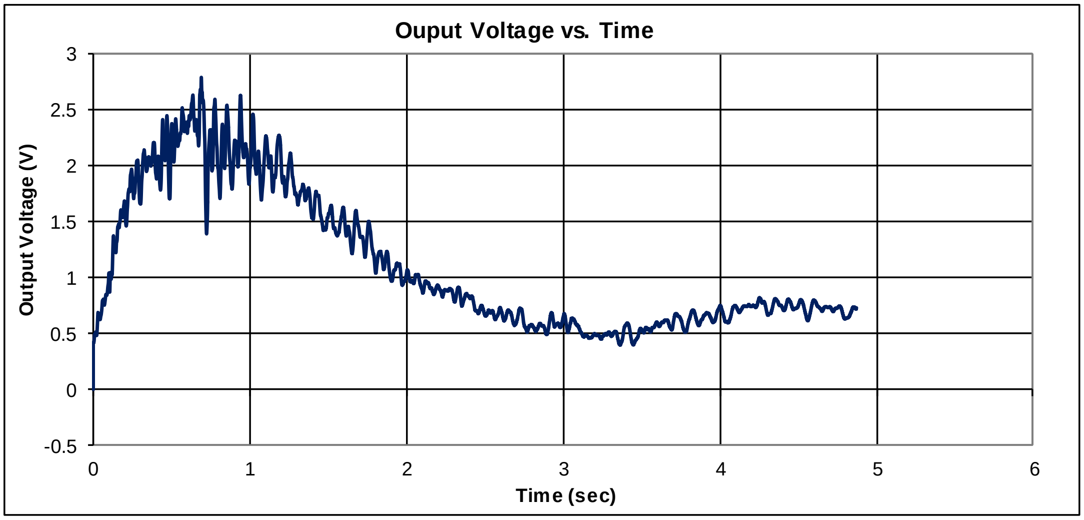
Test No:	MWP-2
Date:	4/18/2014
System / Test Article:	High-Tension, Four-Cable, Median Barrier
LC Location / Component:	Top Cable
Additional Notes:	Load cells were zeroed and then tensioned before the test

Load Cell Information:

Load Cell No.:	143436
Calibration Factor:	2.14575 mv/V
Input Voltage (excitation):	9.98 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	16.27 kips
Time of Max. Load:	0.6898 sec
Event Duration:	4.8719 sec
Final Load:	4.26 kips



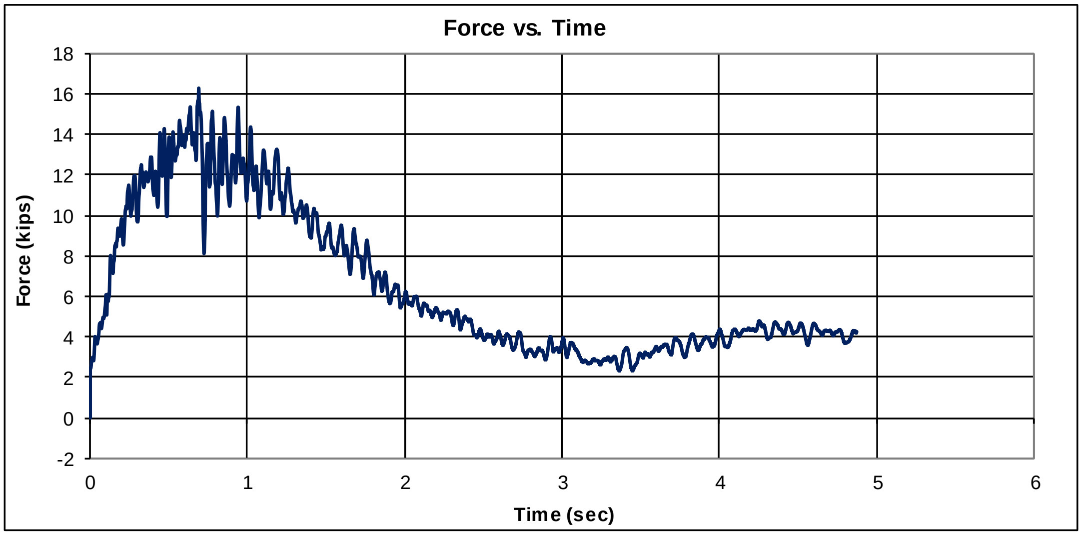


Figure H-2. Load Cell Data, Cable 4, Test No. MWP-2

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

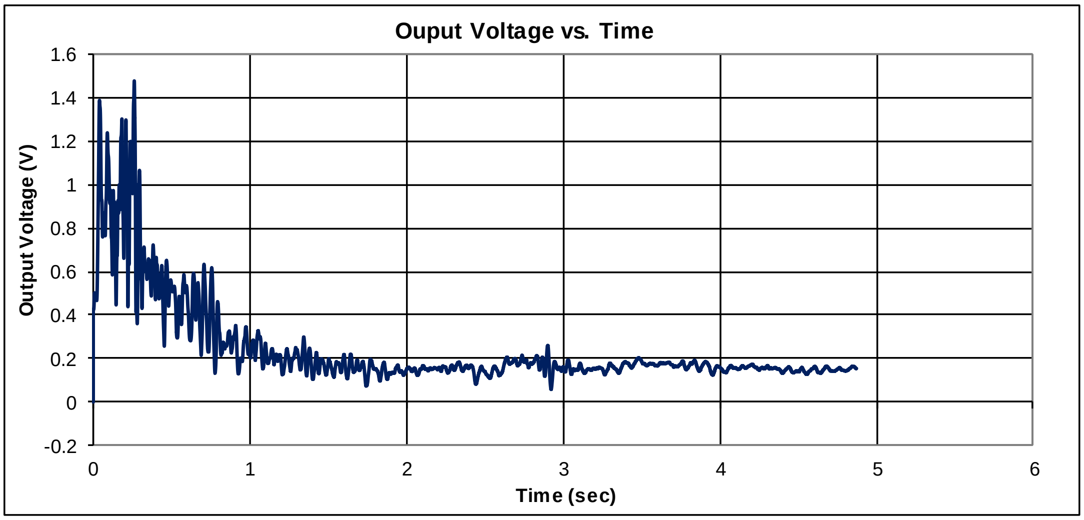
Test No:	MWP-2
Date:	4/18/2014
System / Test Article:	High-Tension, Four-Cable, Median Barrier
LC Location / Component:	Upper Middle Cable
Additional Notes:	Load cells were zeroed and then tensioned before the test

Load Cell Information:

Load Cell No.:	120642
Calibration Factor:	2.12022 mv/V
Input Voltage (excitation):	9.99 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	8.71 kips
Time of Max. Load:	0.2618 sec
Event Duration:	4.8719 sec
Final Load:	0.91 kips



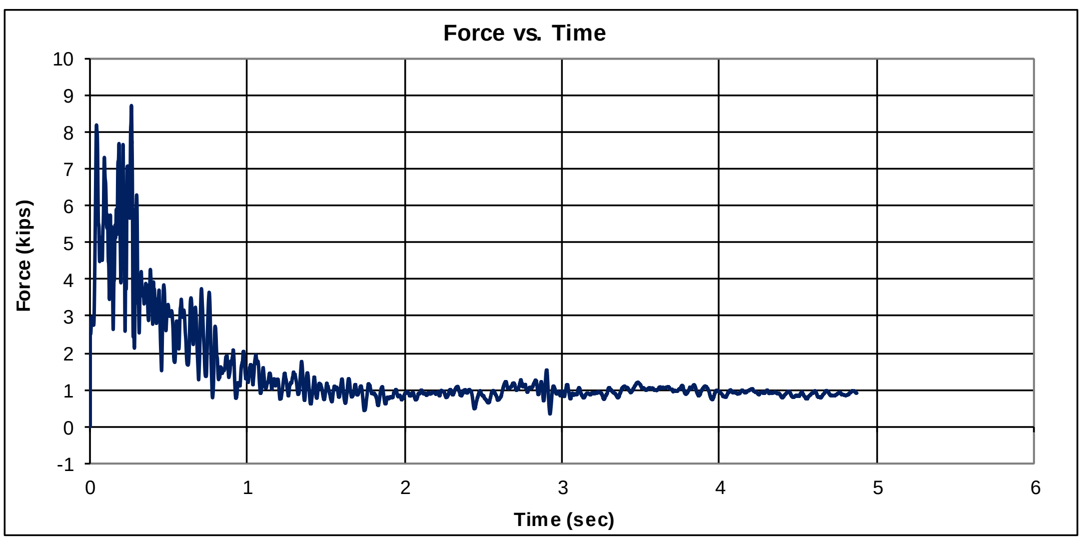


Figure H-3. Load Cell Data, Cable 3, Test No. MWP-2

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

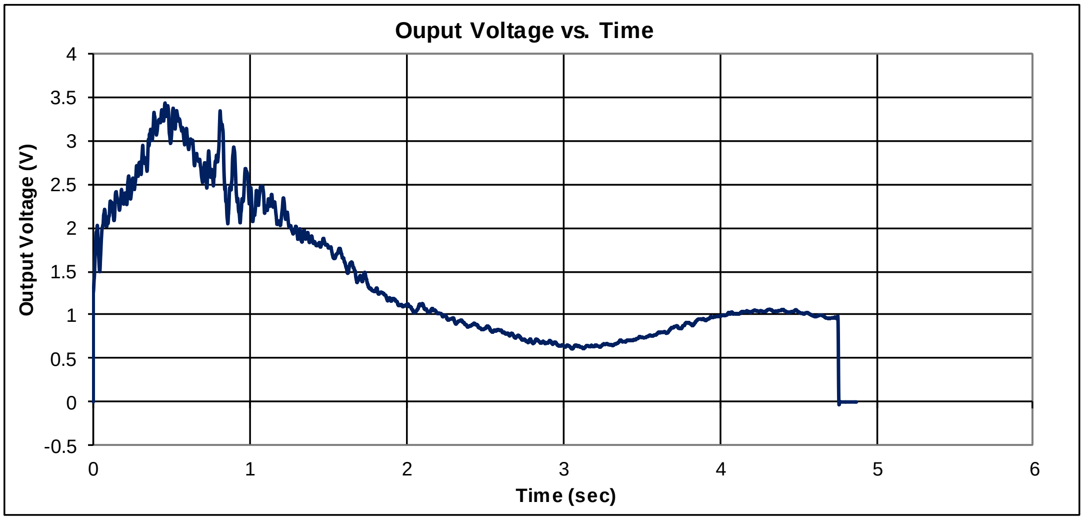
Test No:	MWP-2
Date:	4/18/2014
System / Test Article:	High-Tension, Four-Cable, Median Barrier
LC Location / Component:	Lower Middle Cable
Additional Notes:	Load cells were zeroed and then tensioned before the test

Load Cell Information:

Load Cell No.:	143435
Calibration Factor:	2.15835 mv/V
Input Voltage (excitation):	9.99 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	19.90 kips
Time of Max. Load:	0.4581 sec
Event Duration:	4.8719 sec
Final Load:	0.00 kips



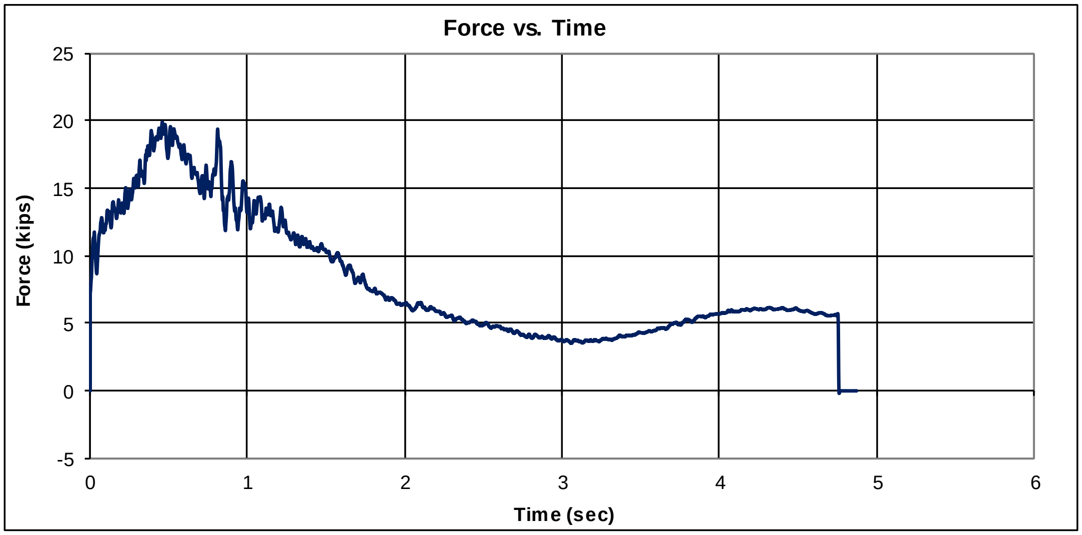


Figure H-4. Load Cell Data, Cable 2, Test No. MWP-2

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

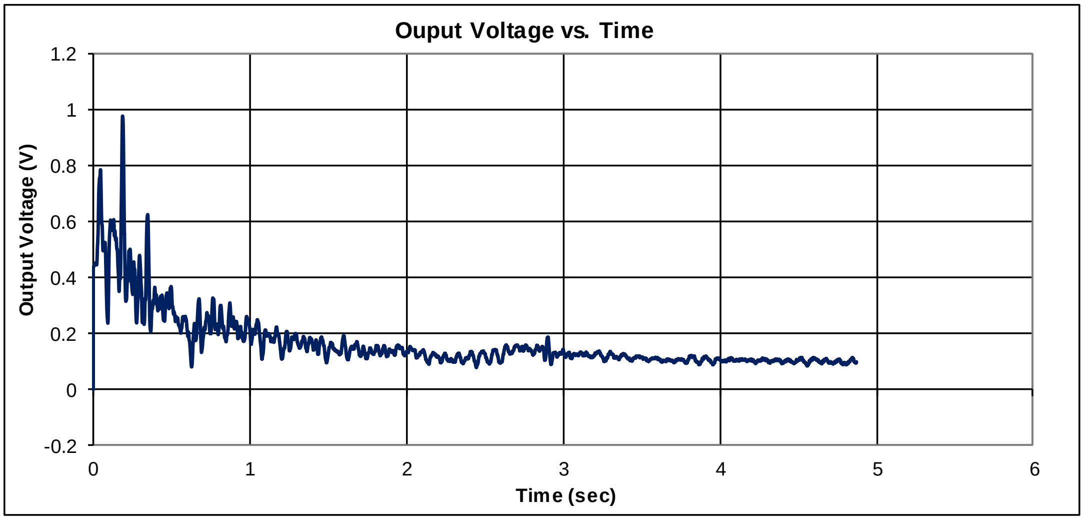
Test No:	MWP-2
Date:	4/18/2014
System / Test Article:	High-Tension, Four-Cable, Median Barrier
LC Location / Component:	Bottom Cable
Additional Notes:	Load cells were zeroed and then tensioned before the test

Load Cell Information:

Load Cell No.:	143435
Calibration Factor:	2.106409 mv/V
Input Voltage (excitation):	9.99 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	5.80 kips
Time of Max. Load:	0.1872 sec
Event Duration:	4.8719 sec
Final Load:	0.59 kips



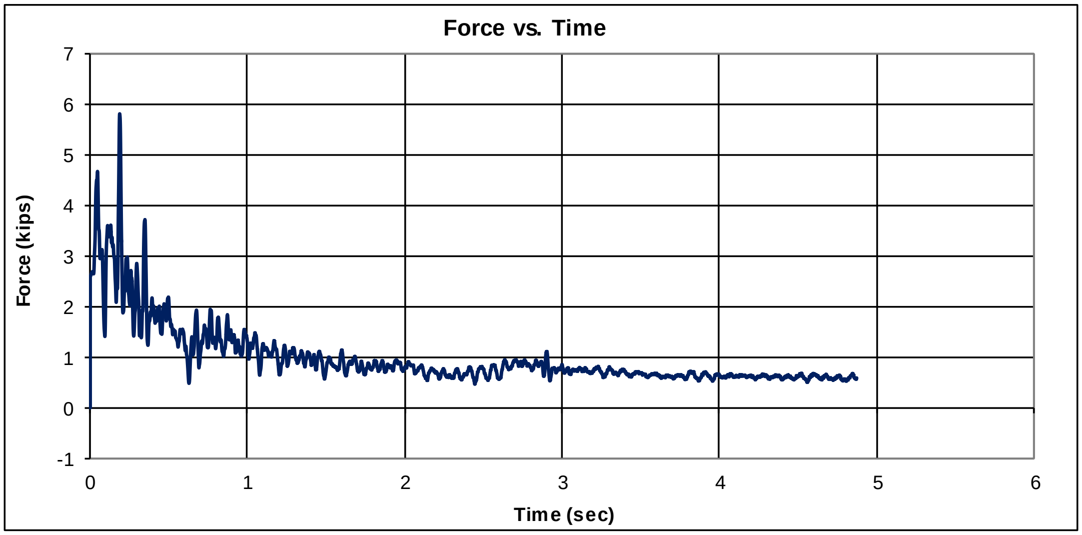


Figure H-5. Load Cell Data, Cable 1, Test No. MWP-2

MIDWEST ROADSIDE SAFETY FACILITY

String Potentiometer Summary

Test Information:

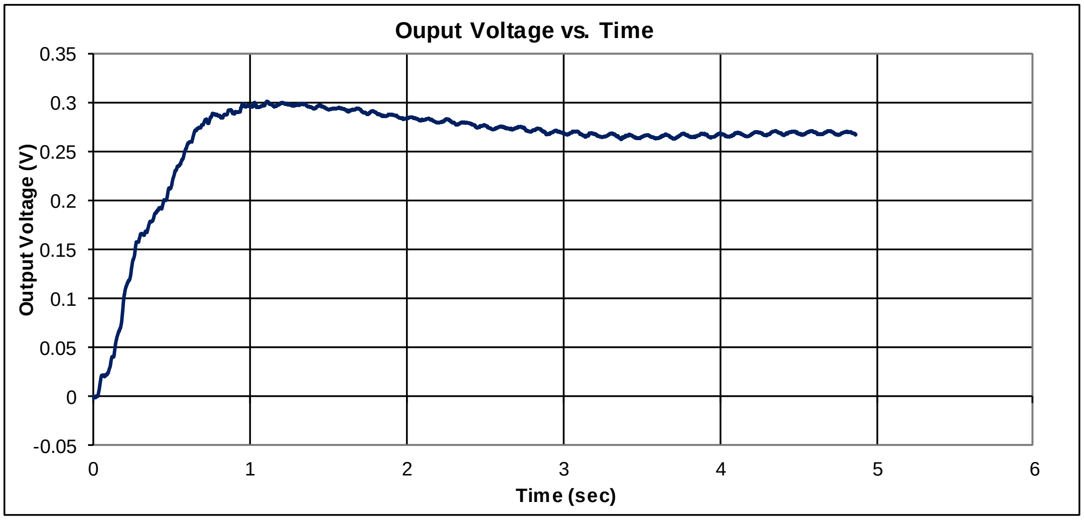
Test No:	MWP-2
Date:	4/18/2014
System / Test Article:	High-Tension, Four-Cable, Median Barrier
SP Location / Component:	Upstream Cable End Anchor
Additional Notes:	NA

String Potentiometer Information:

String Pot No.:	27039202	
Calibration Factor:	19.4483	mV/V/in.
Input Voltage (excitation):	9.98	Volts
Gain:	1	
Full Scale Load:	1	
Sample Rate:	10000	Hz
Cutoff Frequency:	100	Hz

Results:

Max. Displacement:	1.55 in.
Time of Max. Displacement:	1.1086 sec
Event Duration:	4.8669 sec
Final Displacement:	1.38 in.



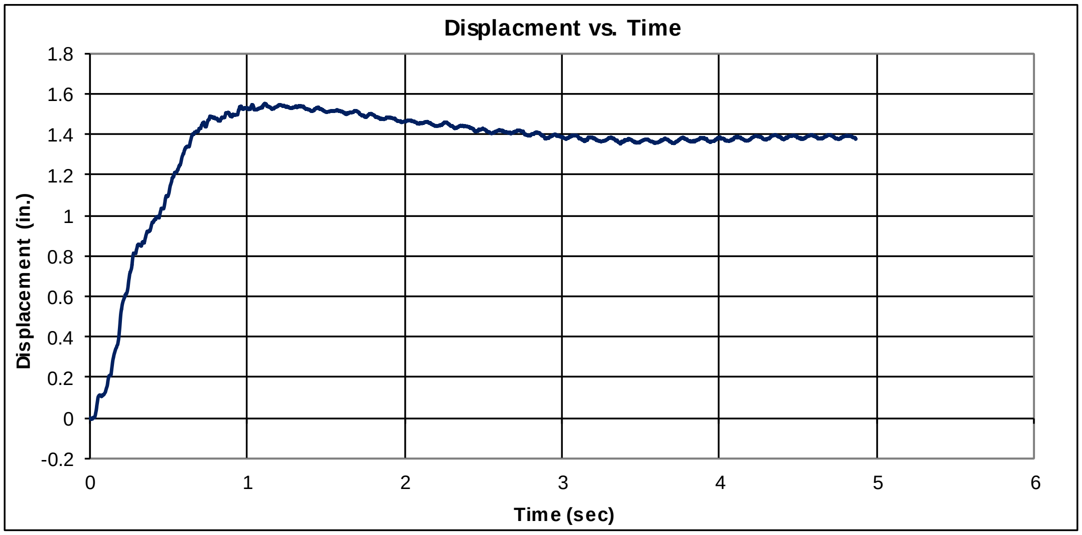


Figure H-6. String Potentiometer Data, Test No. MWP-2

Appendix I. Accelerometer and Rate Transducer Data Plots, Test No. MWP-3

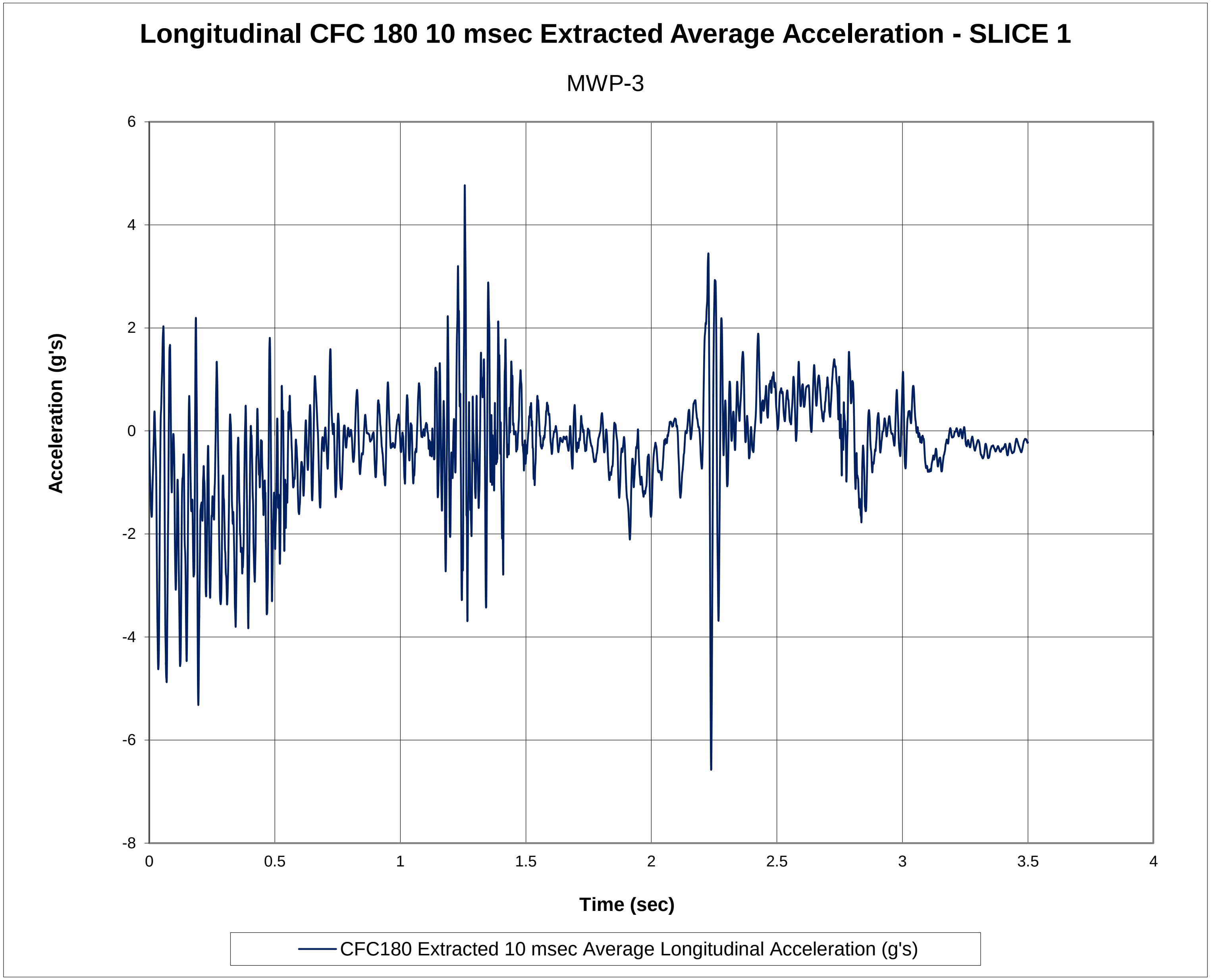


Figure I-1. 10-ms Average Longitudinal Deceleration (SLICE 1), Test No. MWP-3

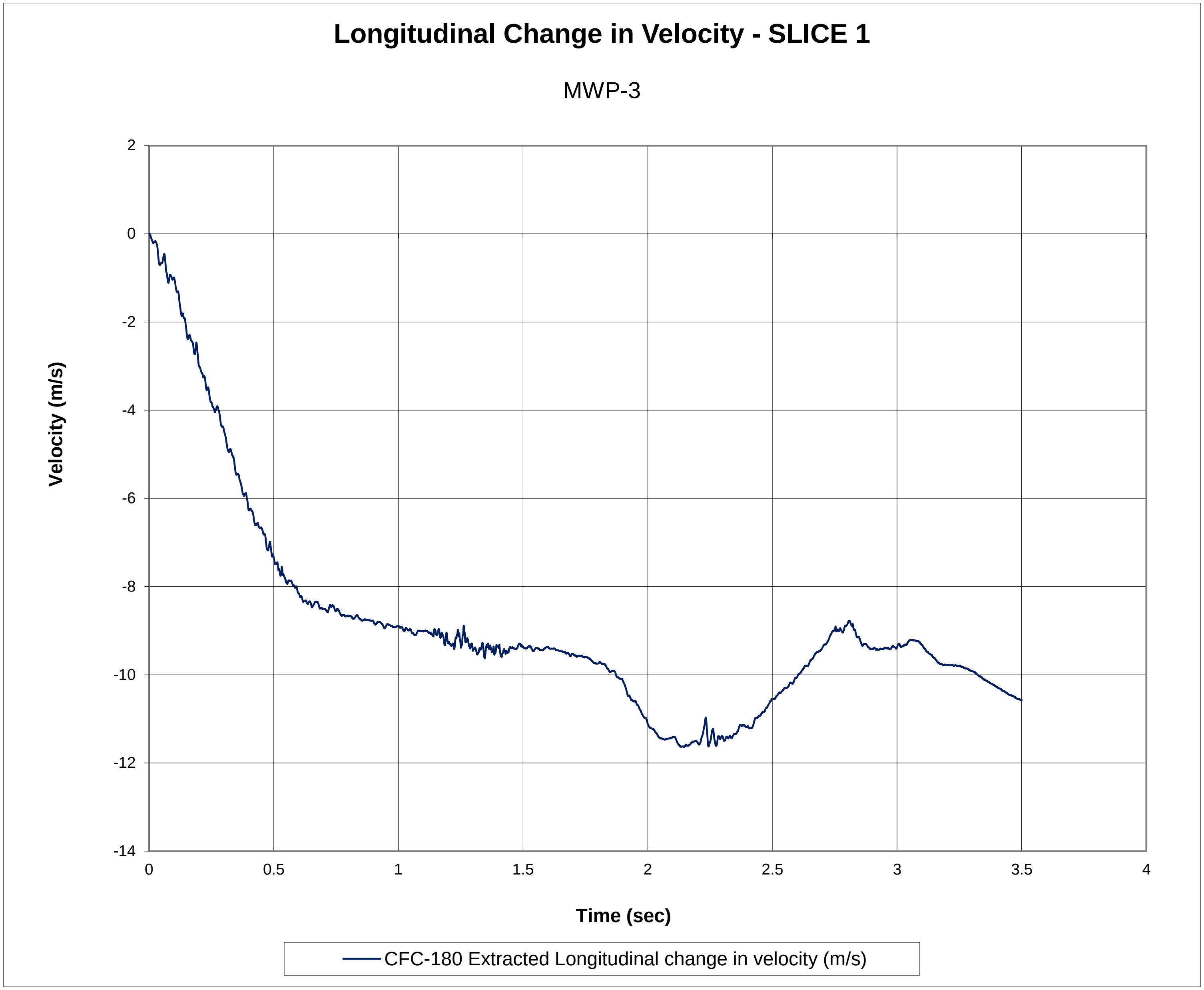


Figure I-2. Longitudinal Occupant Impact Velocity (SLICE 1), Test No. MWP-3

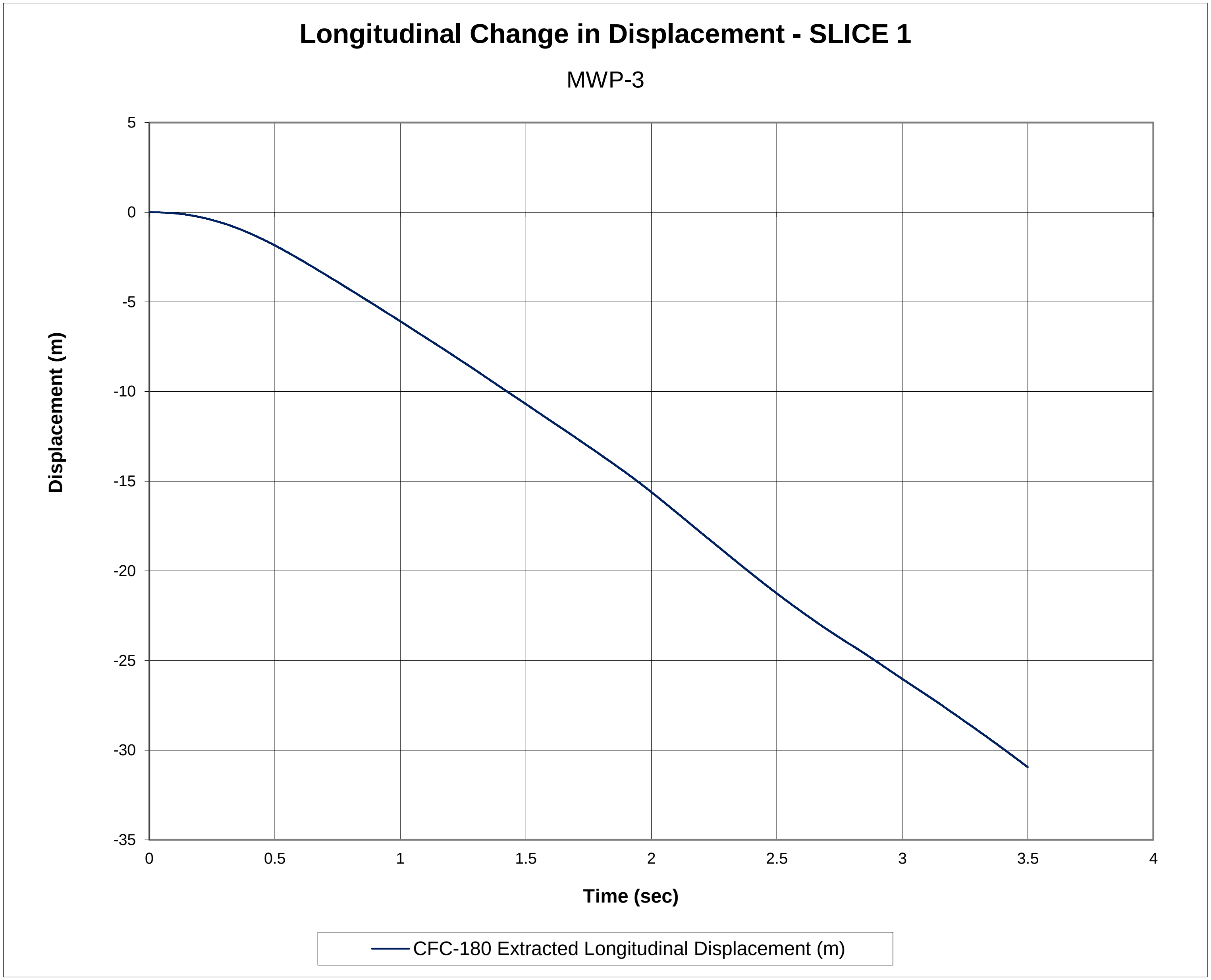


Figure I-3. Longitudinal Occupant Displacement (SLICE 1), Test No. MWP-3

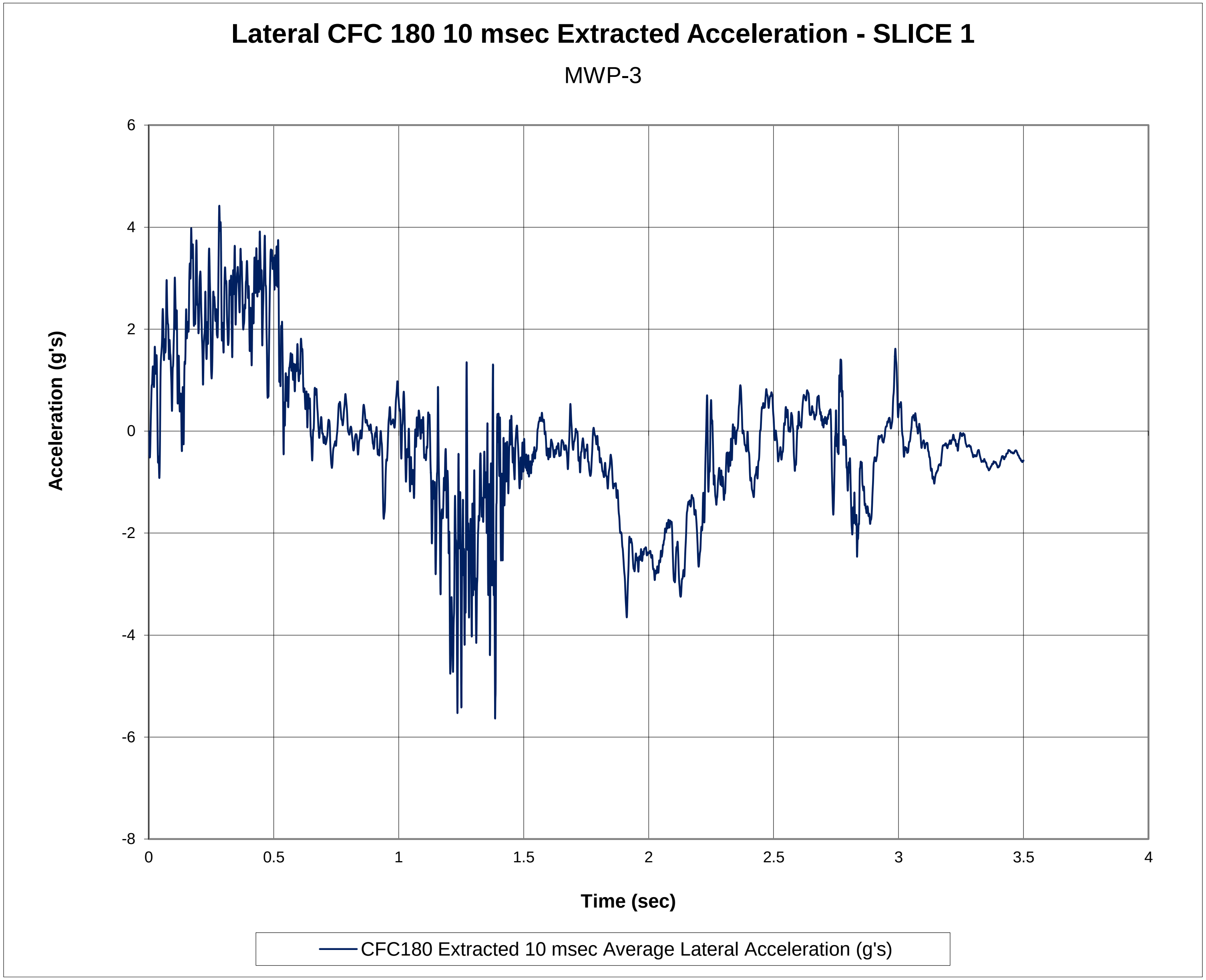


Figure I-4. 10-ms Average Lateral Deceleration (SLICE 1), Test No. MWP-3

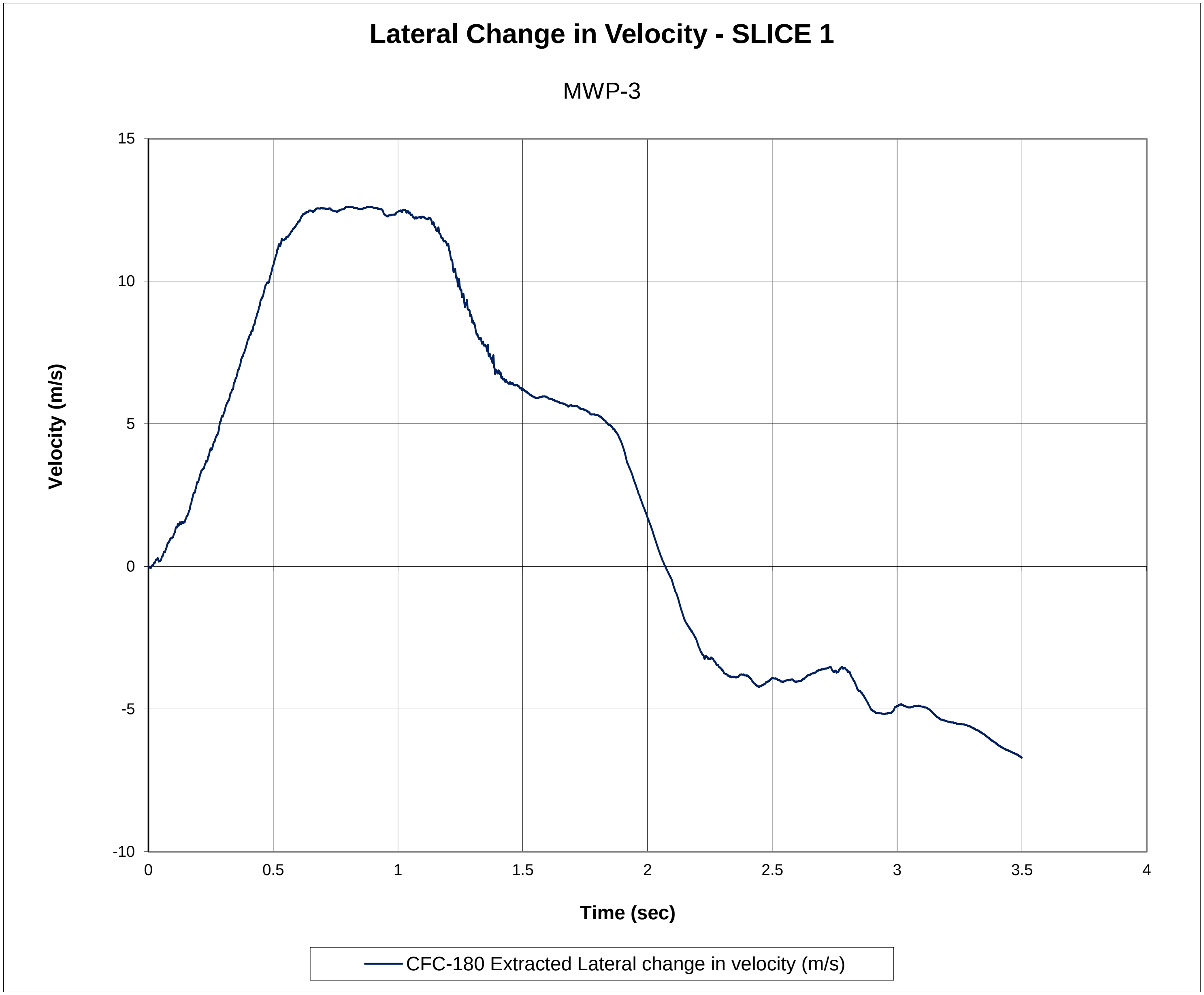


Figure I-5. Lateral Occupant Impact Velocity (SLICE 1), Test No. MWP-3

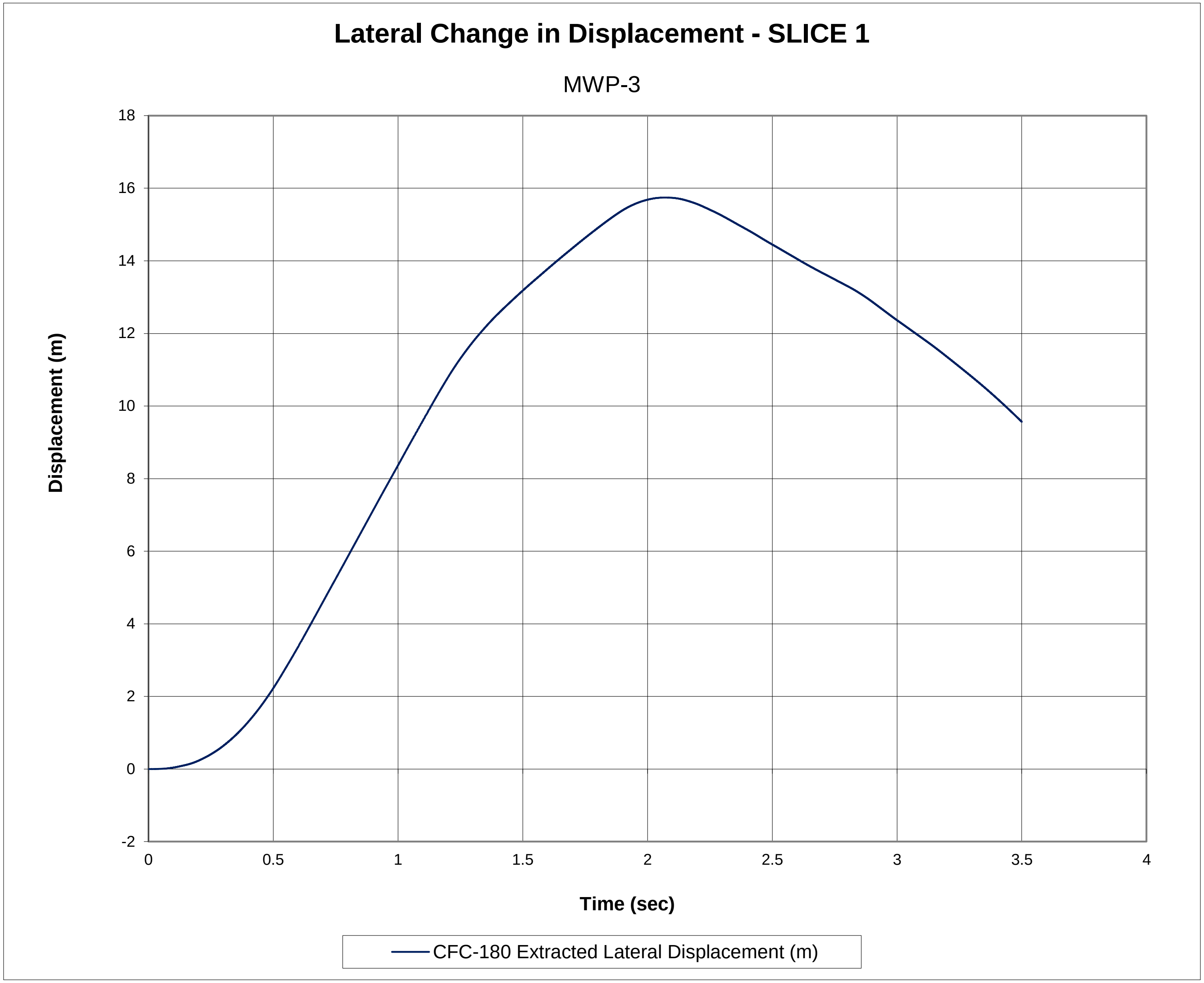


Figure I-6. Lateral Occupant Displacement (SLICE 1), Test No. MWP-3

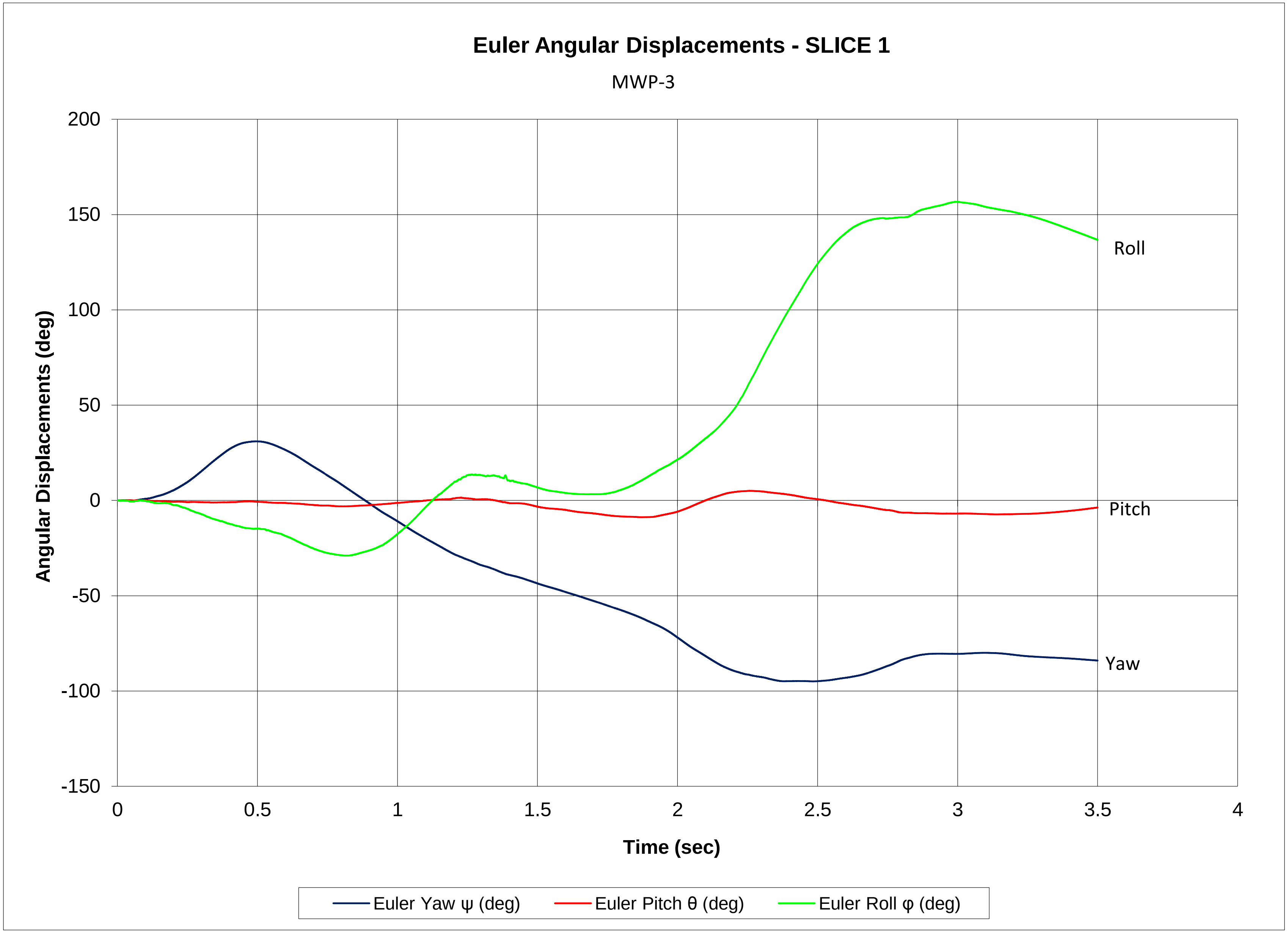


Figure I-7. Vehicle Angular Displacements (SLICE 1), Test No. MWP-3

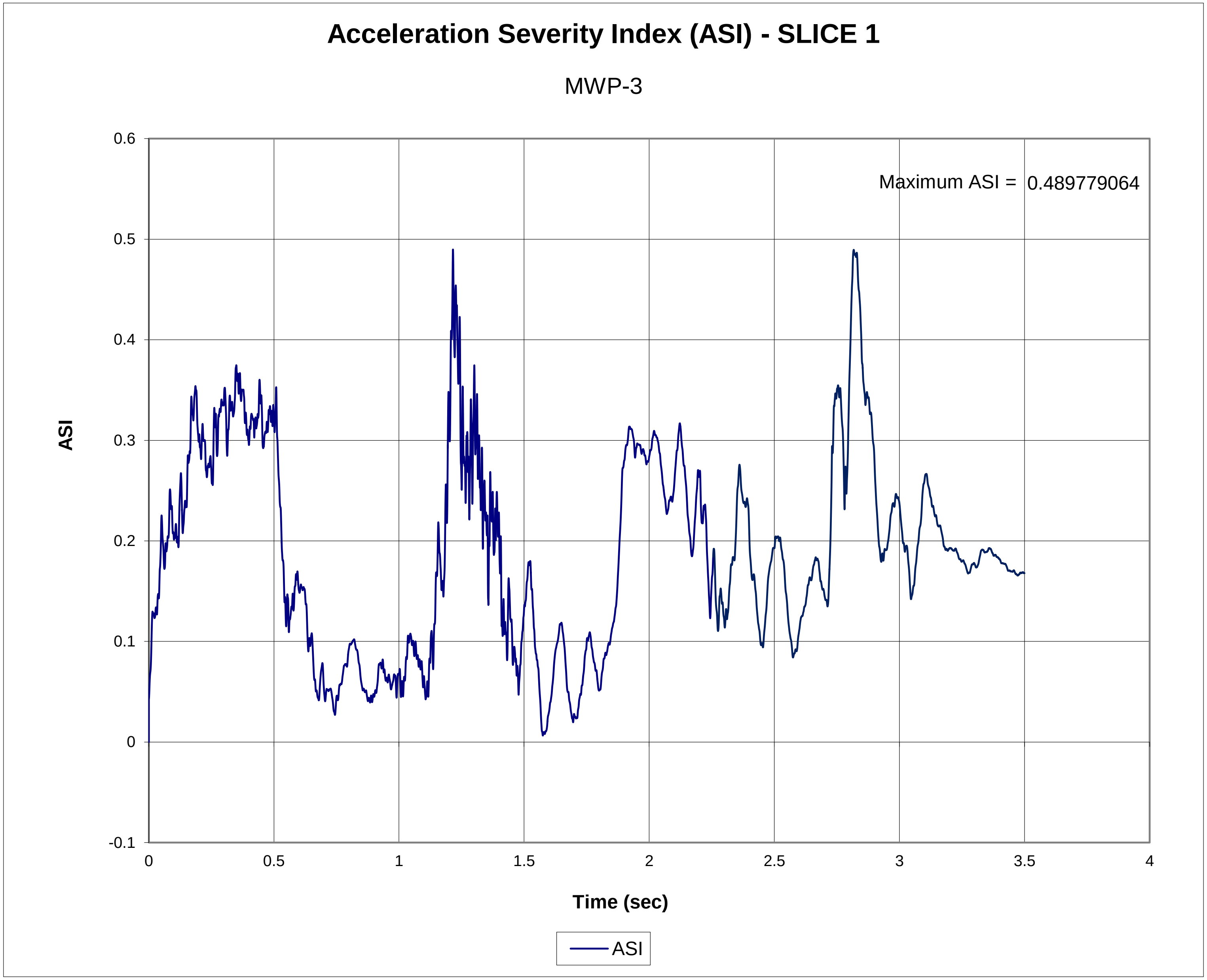


Figure I-8. Acceleration Severity Index (SLICE 1), Test No. MWP-3

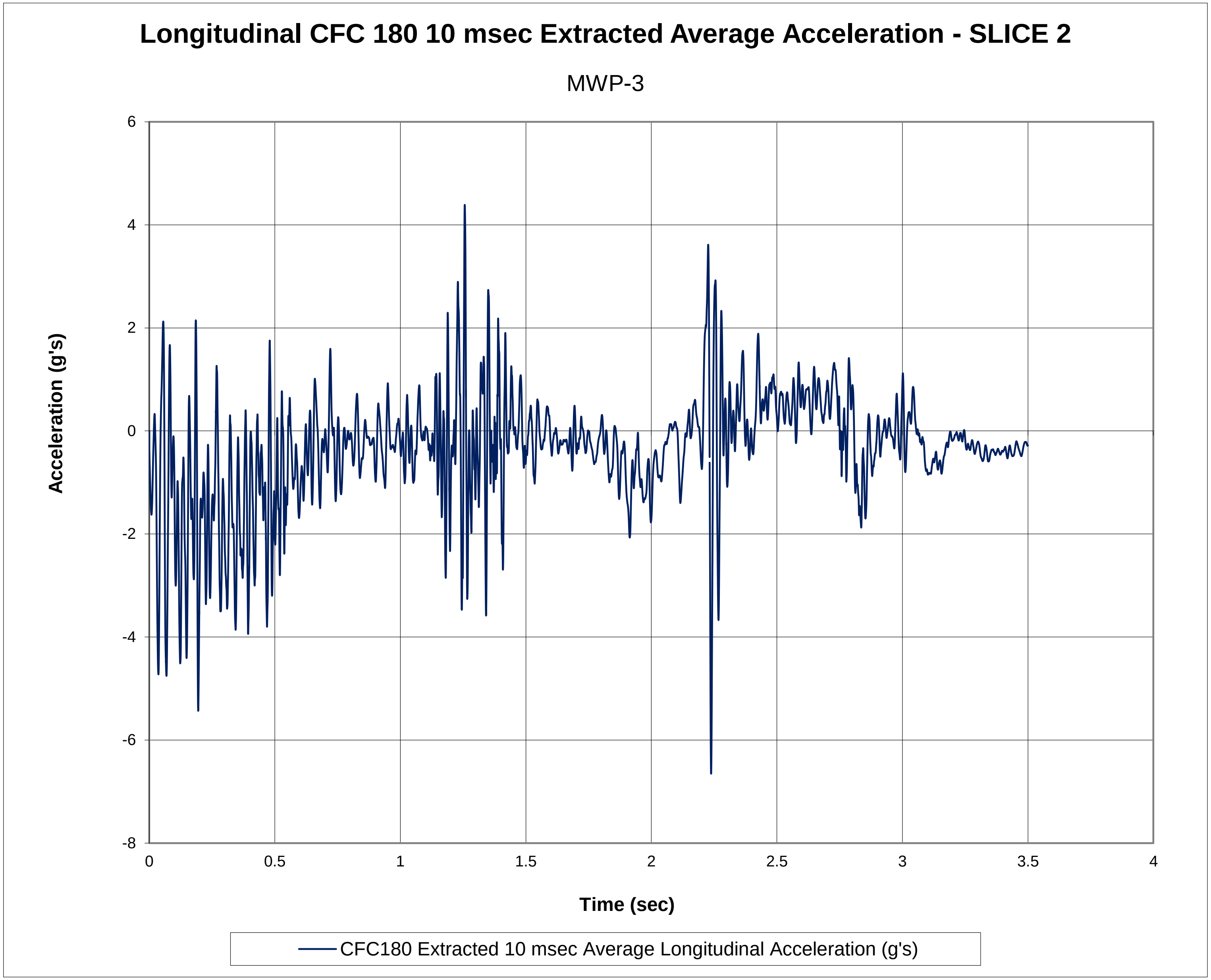


Figure I-9. 10-ms Average Longitudinal Deceleration (SLICE 2), Test No. MWP-3

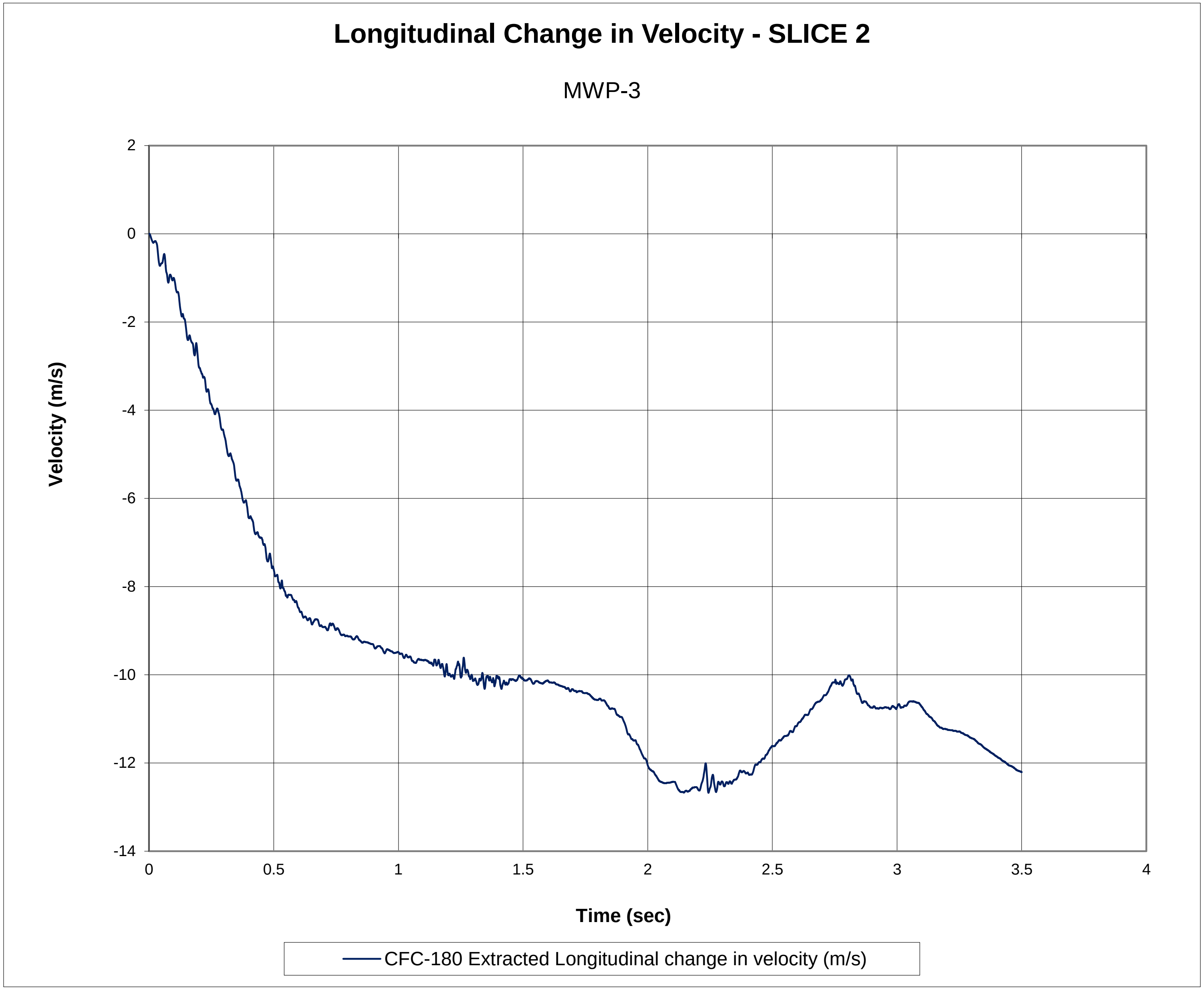


Figure I-10. Longitudinal Occupant Impact Velocity (SLICE 2), Test No. MWP-3

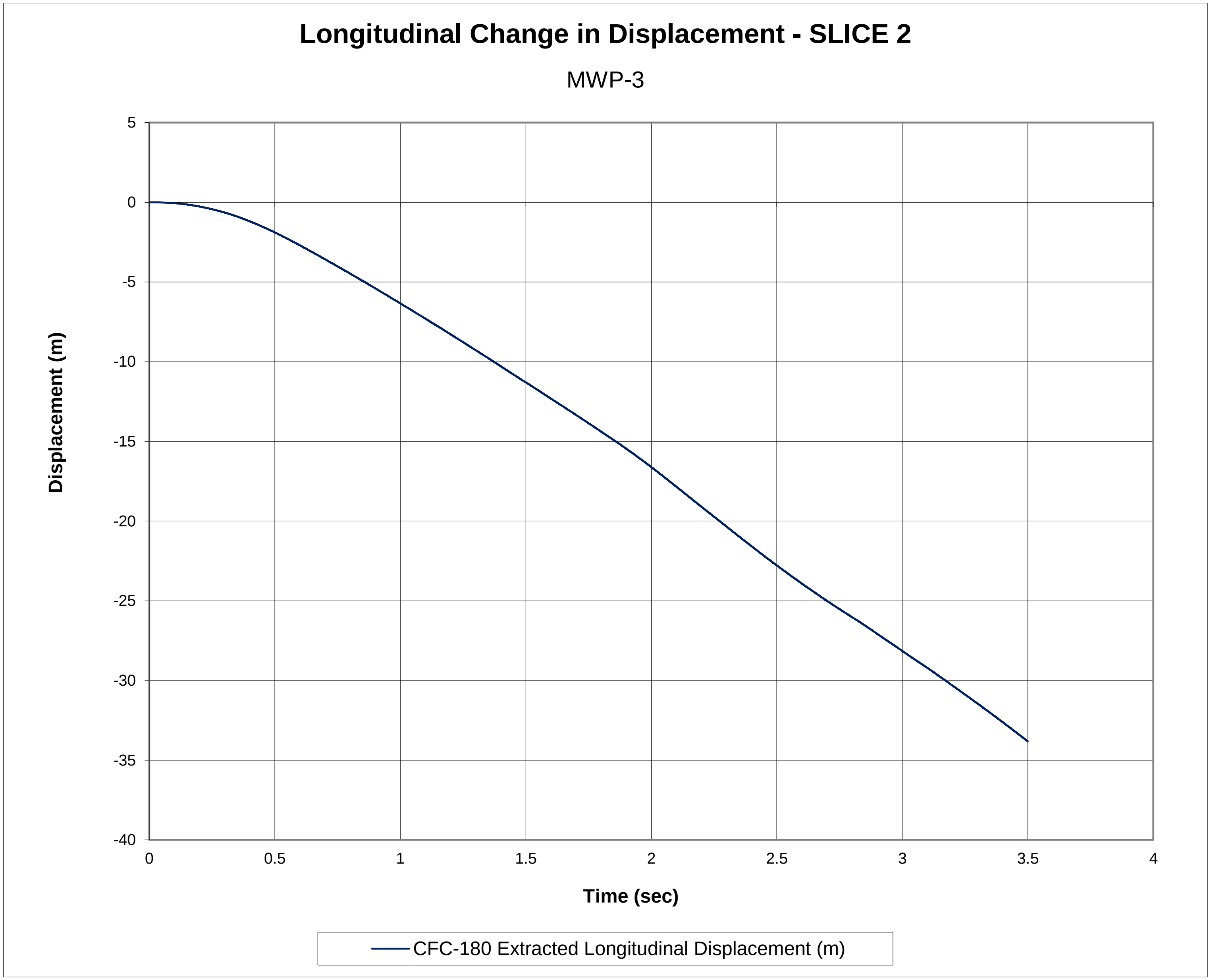


Figure I-11. Longitudinal Occupant Displacement (SLICE 2), Test No. MWP-3

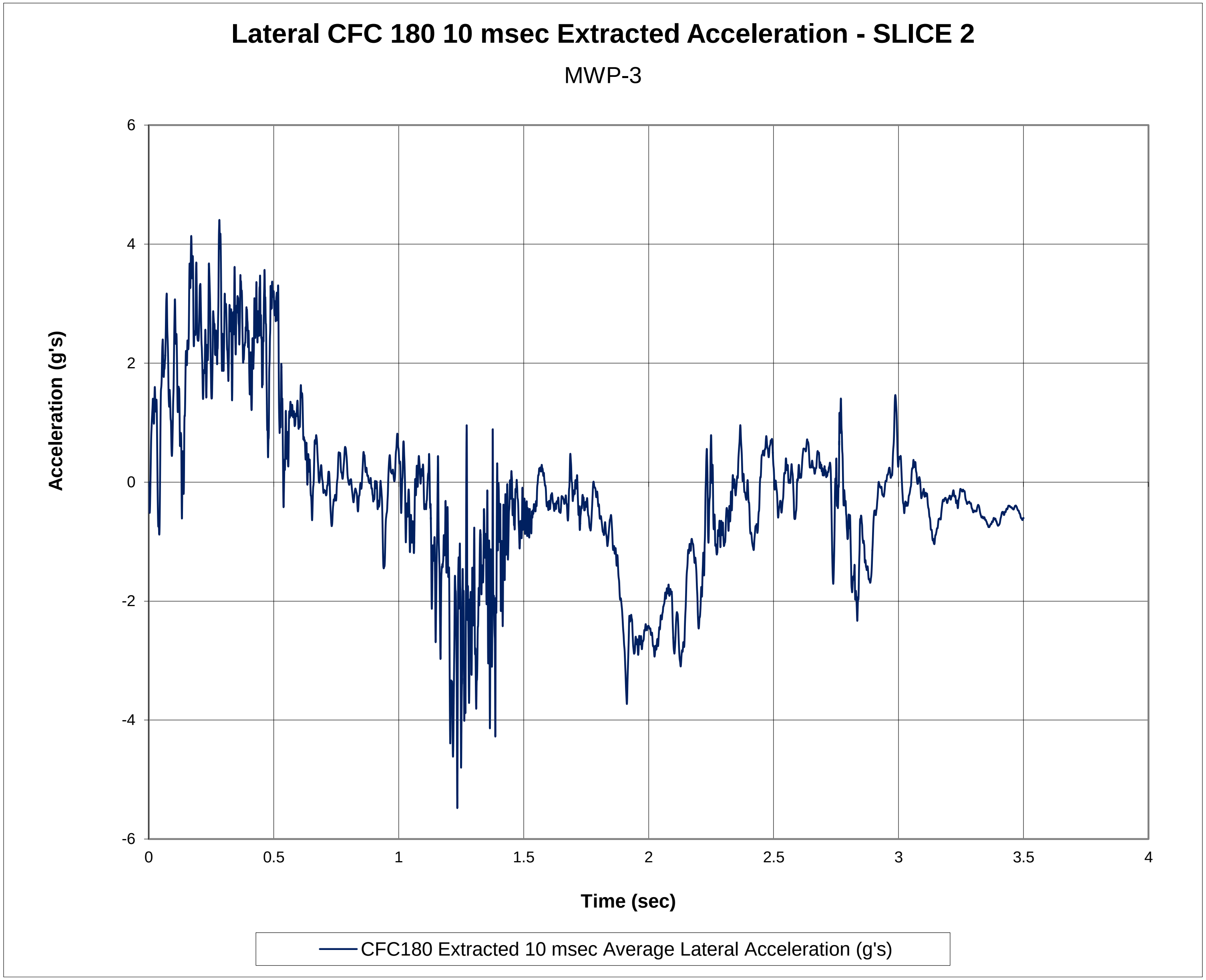


Figure I-12. 10-ms Average Lateral Deceleration (SLICE 2), Test No. MWP-3

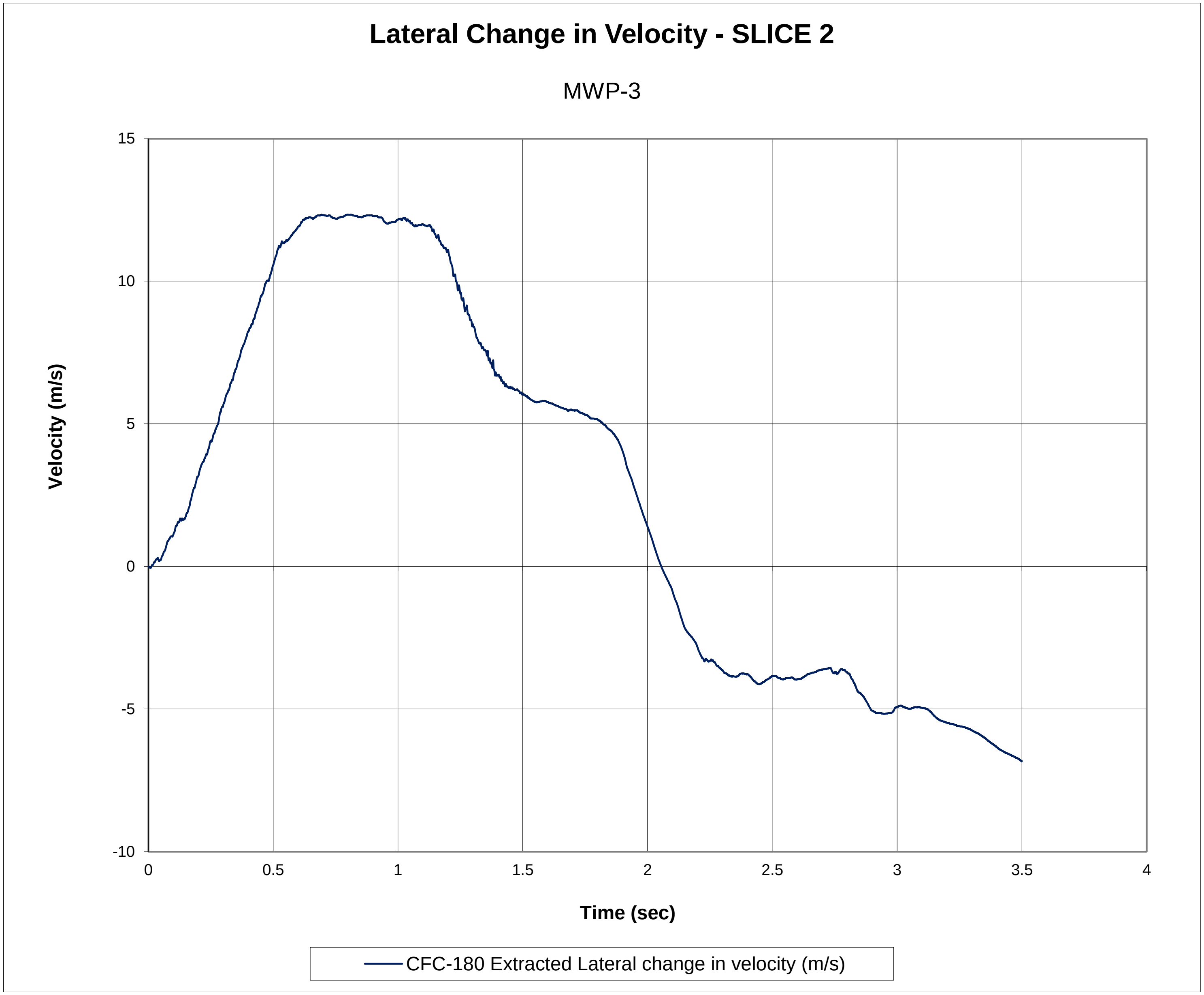


Figure I-13. Lateral Occupant Impact Velocity (SLICE 2), Test No. MWP-3

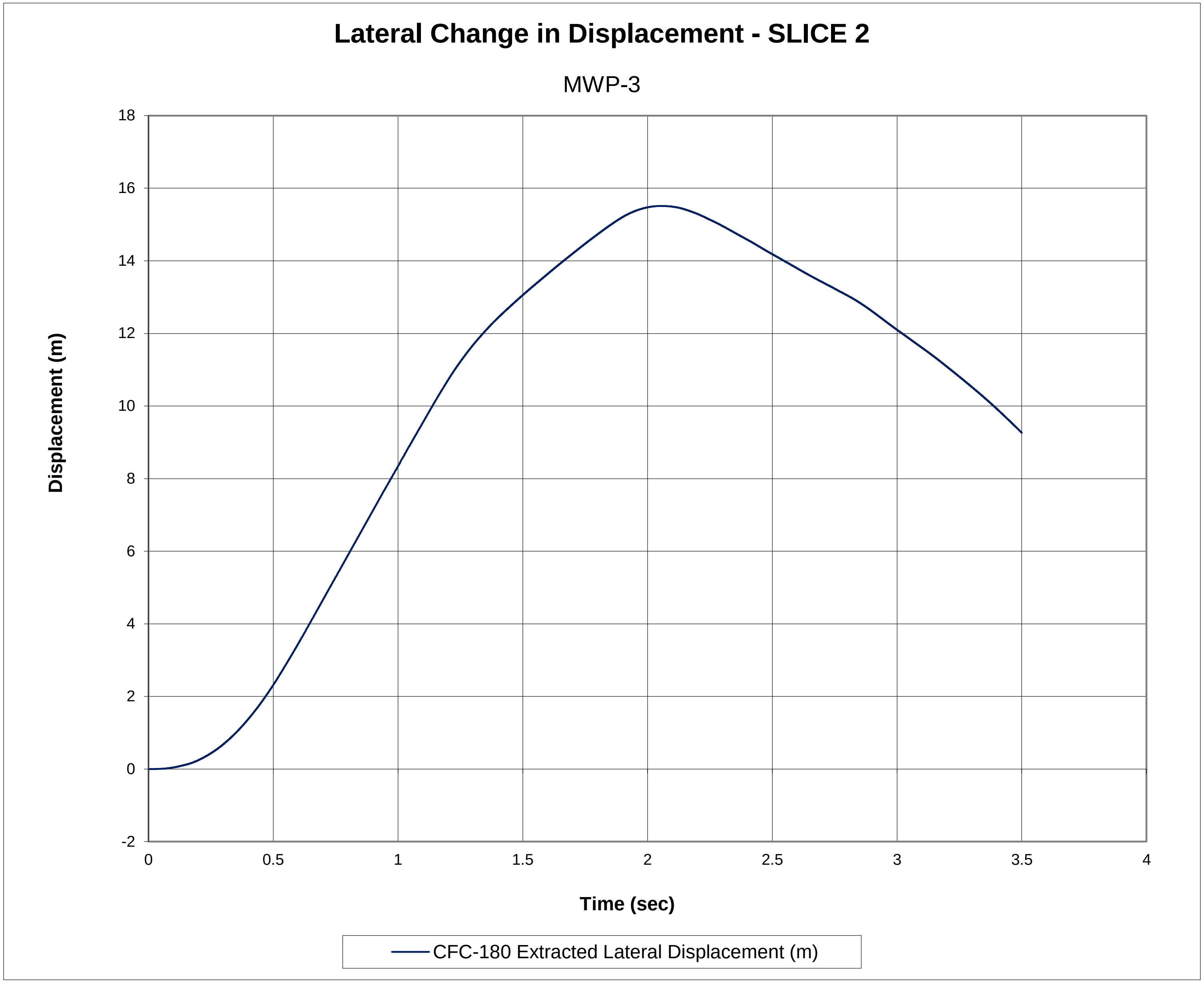


Figure I-14. Lateral Occupant Displacement (SLICE 2), Test No. MWP-3

Figure I-15. Vehicle Angular Displacements (SLICE 2), Test No. MWP-3

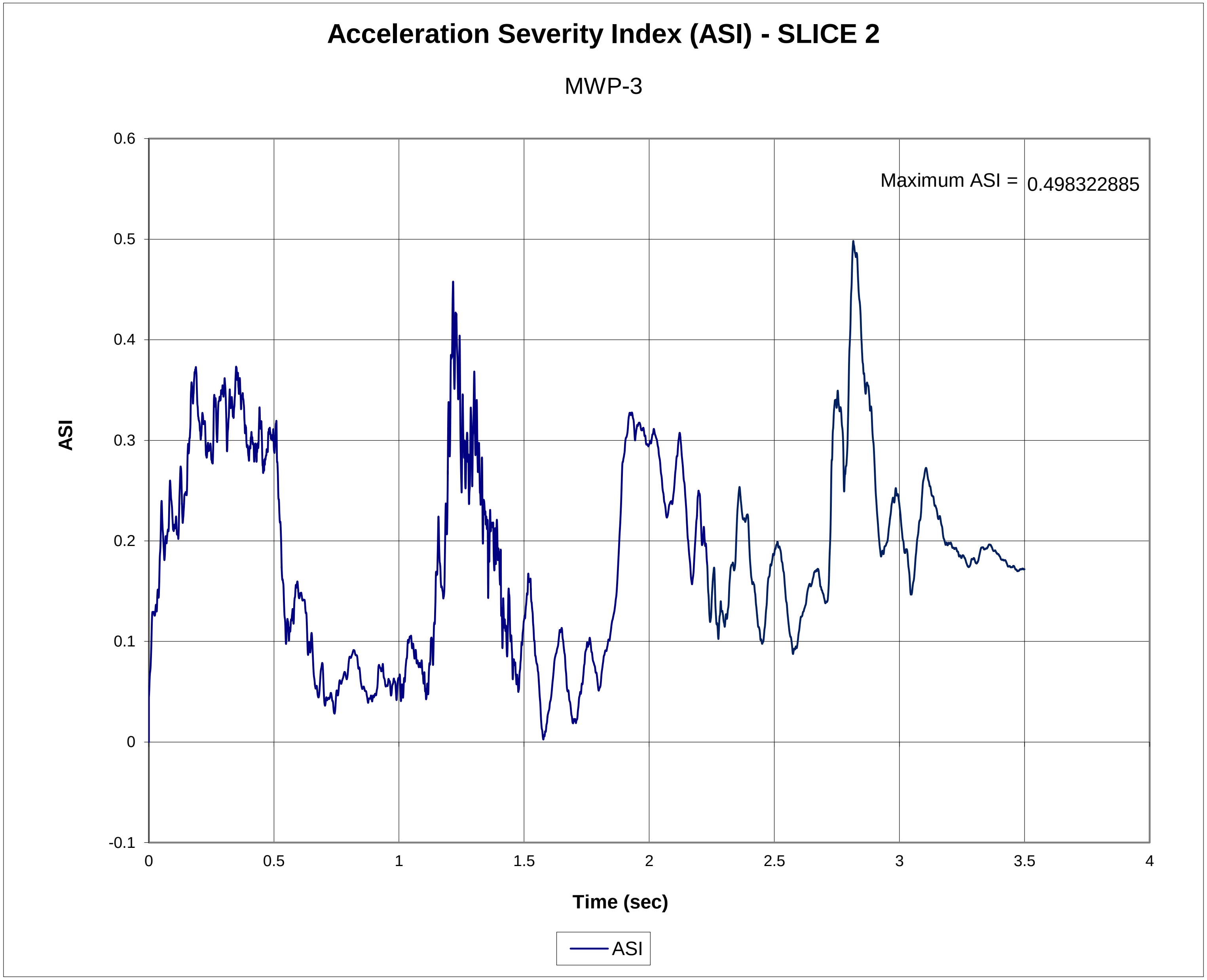


Figure I-16. Acceleration Severity Index (SLICE 2), Test No. MWP-3

Appendix J. Load Cell and String Potentiometer Data, Test No. MWP-3

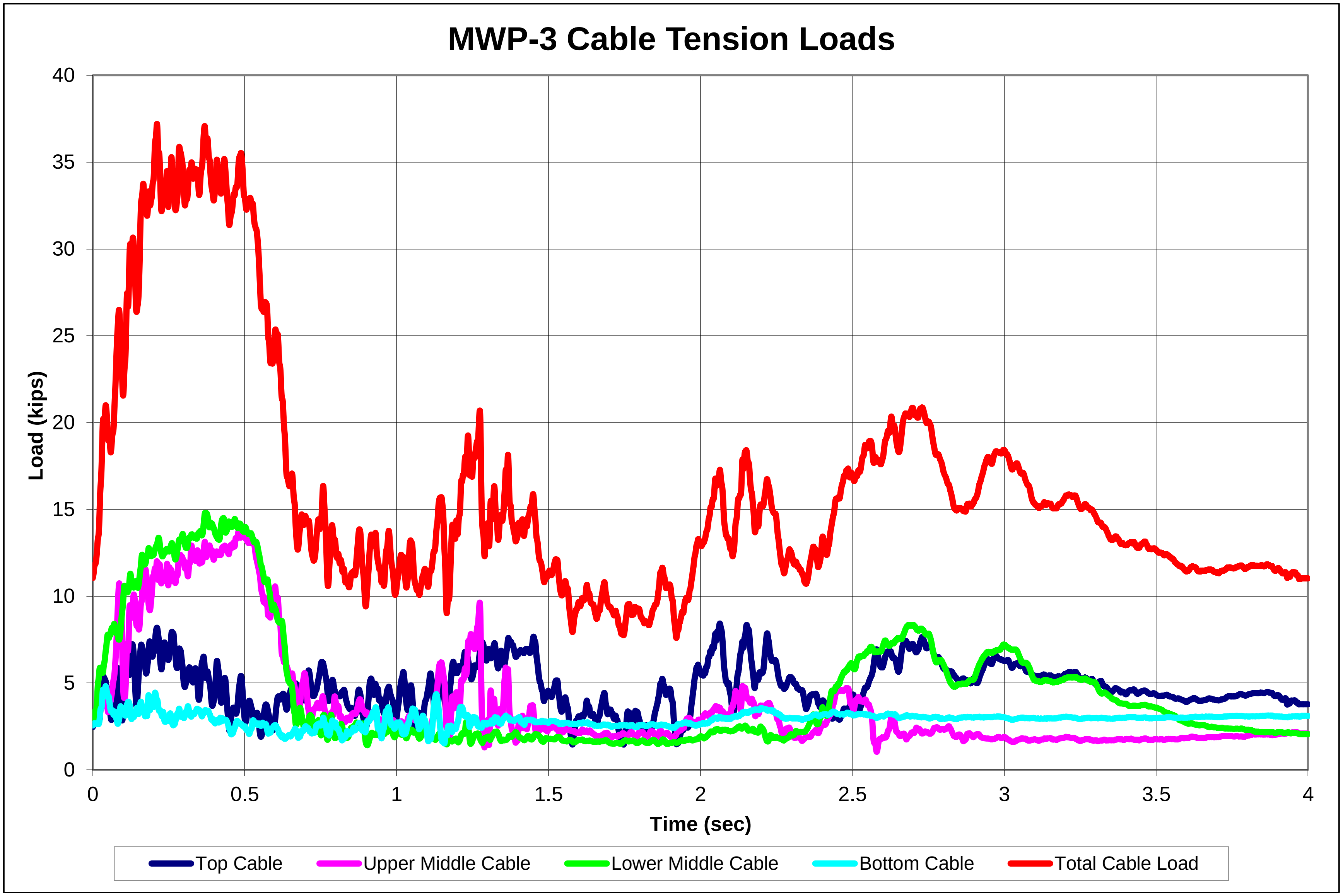


Figure J-1. Combined Load Cell Data, Test No. MWP-3

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

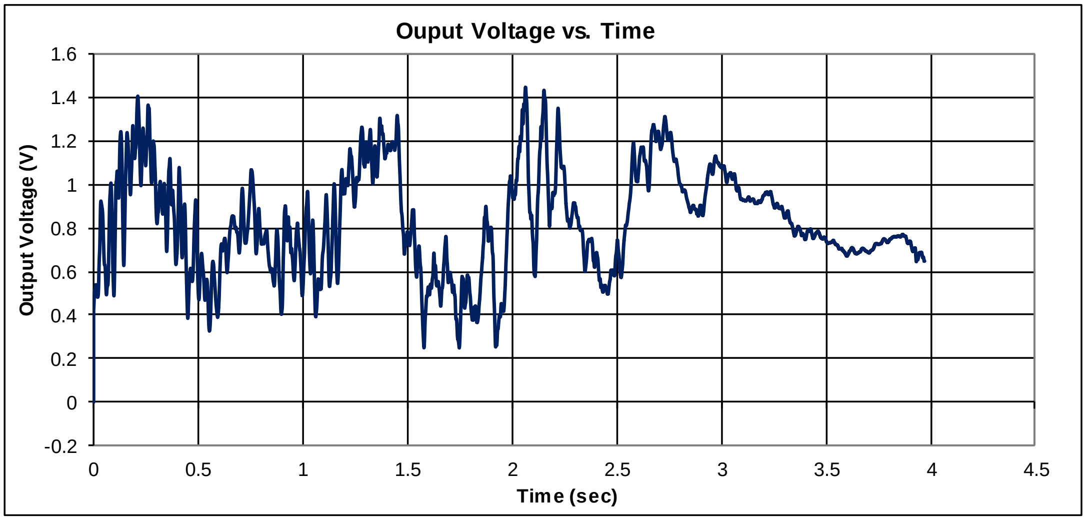
Test No:	MWP-3
Date:	7/11/2014
System / Test Article:	4-cable median barrier
LC Location / Component:	Top Cable - US of Impact
Additional Notes:	Load cells were zeroed and then tensioned before the test.

Load Cell Information:

Load Cell No.:	143436
Calibration Factor:	2.14575 mv/V
Input Voltage (excitation):	10 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	8.42 kips
Time of Max. Load:	2.0642 sec
Event Duration:	3.971 sec
Final Load:	3.78 kips



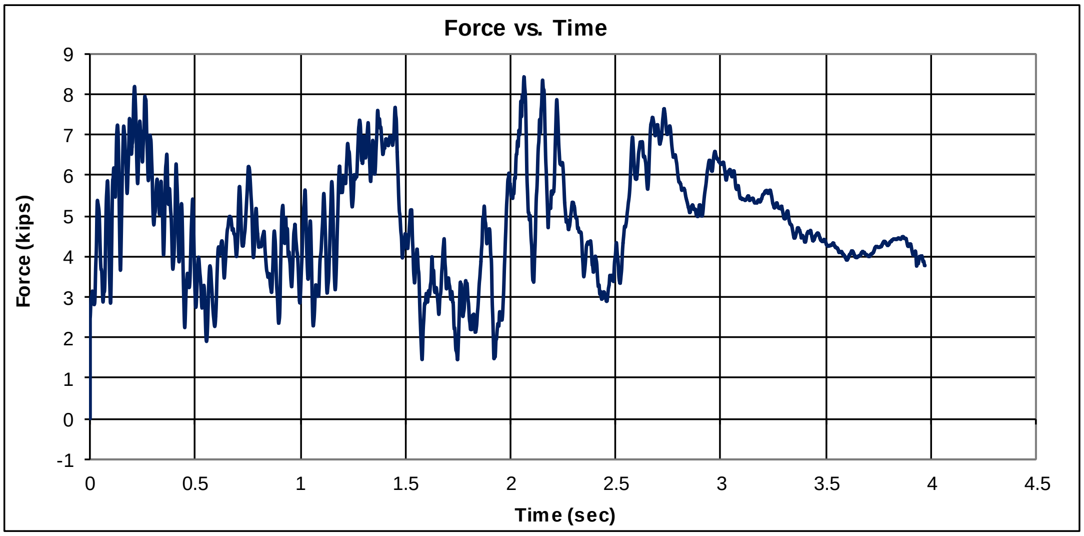


Figure J-2. Load Cell Data, Cable 4, Test No. MWP-3

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

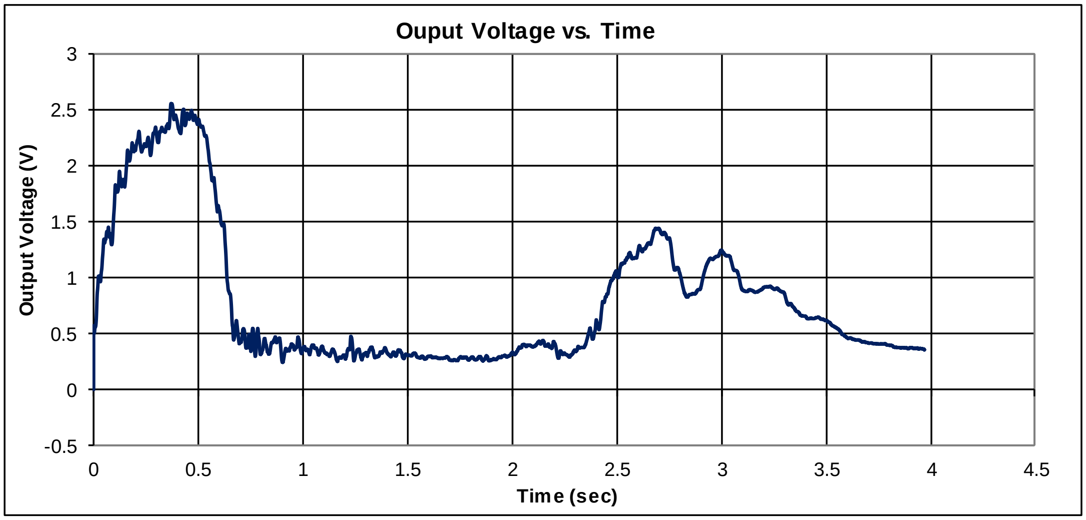
Test No:	MWP-3
Date:	7/11/2014
System / Test Article:	4-cable median barrier
LC Location / Component:	Lower Middle Cable - US of Impact
Additional Notes:	Load cells were zoeroed and then tensioned before the test.

Load Cell Information:

Load Cell No.:	143435
Calibration Factor:	2.15835 mv/V
Input Voltage (excitation):	10 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	14.80 kips
Time of Max. Load:	0.3698 sec
Event Duration:	3.971 sec
Final Load:	2.06 kips



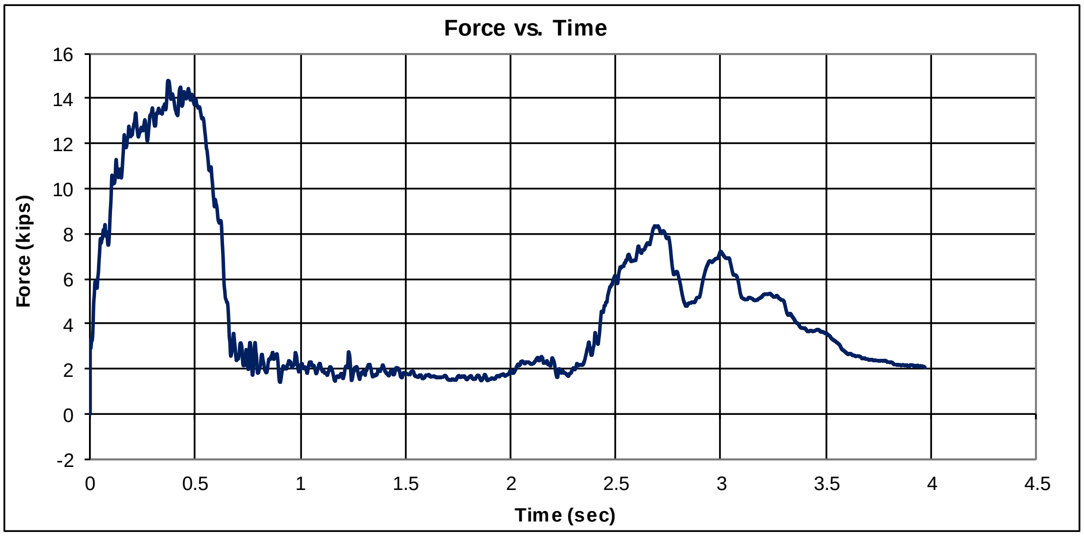


Figure J-3. Load Cell Data, Cable 3, Test No. MWP-3

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

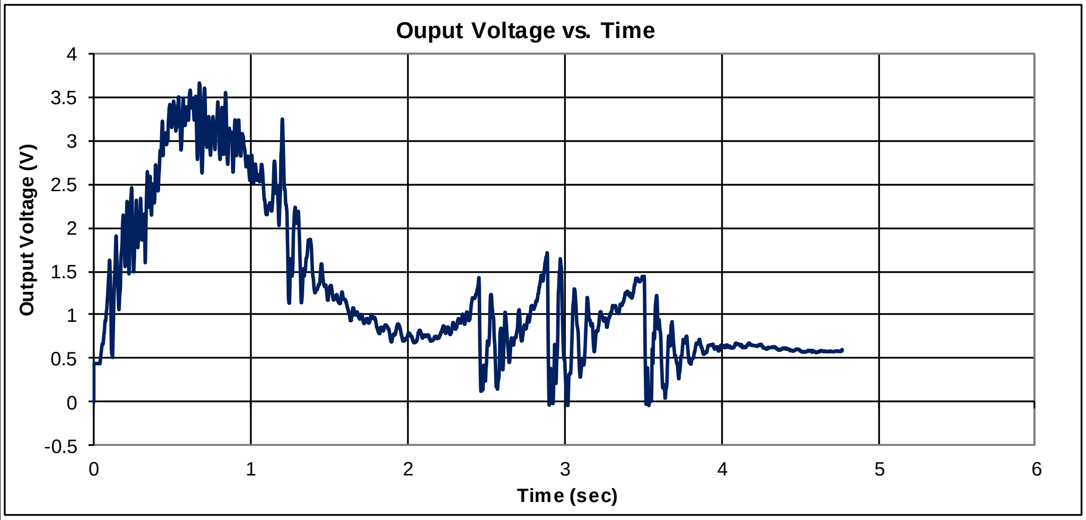
Test No:	MWP-1
Date:	3/26/2014
System / Test Article:	4 Cable Barrier - 3rd Cable from Top
LC Location / Component:	Between post nos. 4 and 5
Additional Notes:	Load cells were zeroed and then tensioned before the test.

Load Cell Information:

Load Cell No.:	143433
Calibration Factor:	2.16517 mv/V
Input Voltage (excitation):	10 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	21.15 kips
Time of Max. Load:	0.6732 sec
Event Duration:	4.7691 sec
Final Load:	3.48 kips



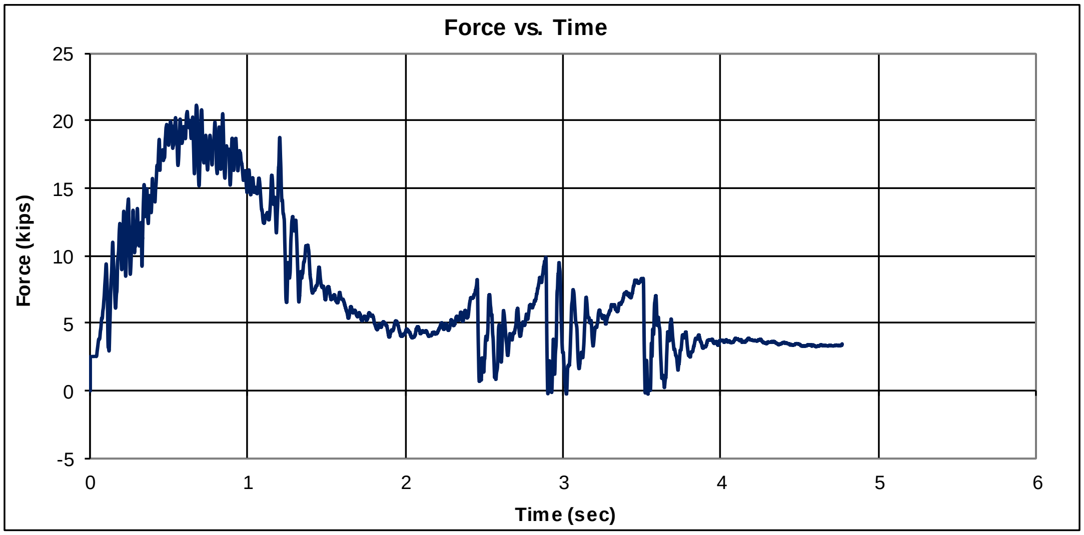


Figure J-4. Load Cell Data, Cable 2, Test No. MWP-3

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

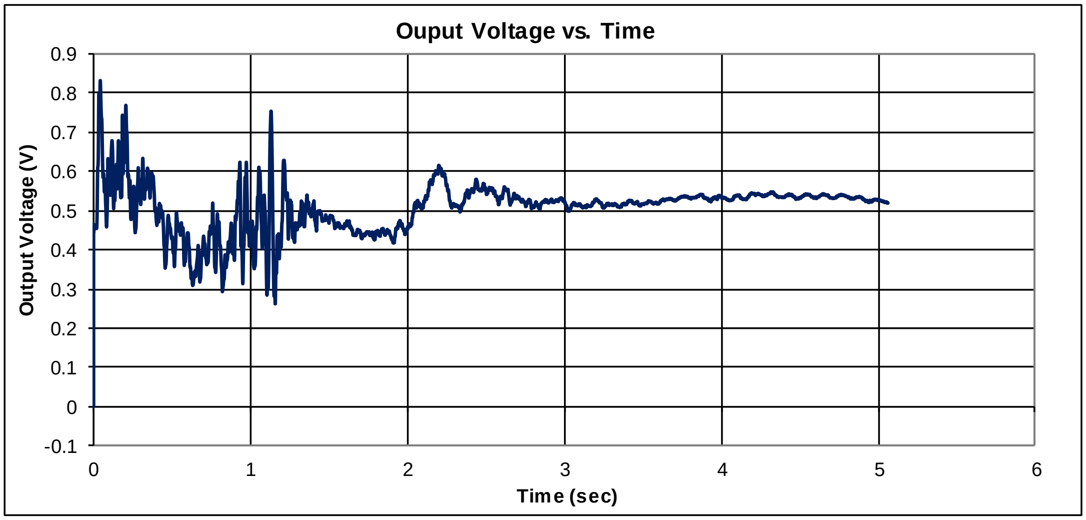
Test No:	MWP-3
Date:	7/11/2014
System / Test Article:	4-cable median barrier
LC Location / Component:	Bottom Cable - US of Impact
Additional Notes:	Load cells were zeroed and then tensioned before the test.

Load Cell Information:

Load Cell No.:	143432
Calibration Factor:	2.15992 mv/V
Input Voltage (excitation):	10 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	4.81 kips
Time of Max. Load:	0.0425 sec
Event Duration:	5.061 sec
Final Load:	3.01 kips



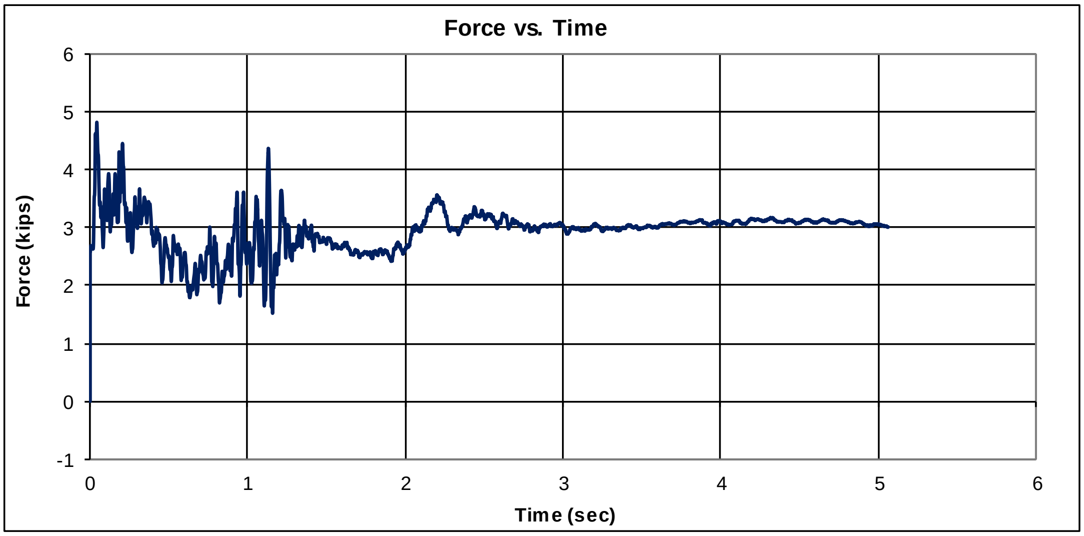


Figure J-5. Load Cell Data, Cable 1, Test No. MWP-3

MIDWEST ROADSIDE SAFETY FACILITY

String Potentiometer Summary

Test Information:

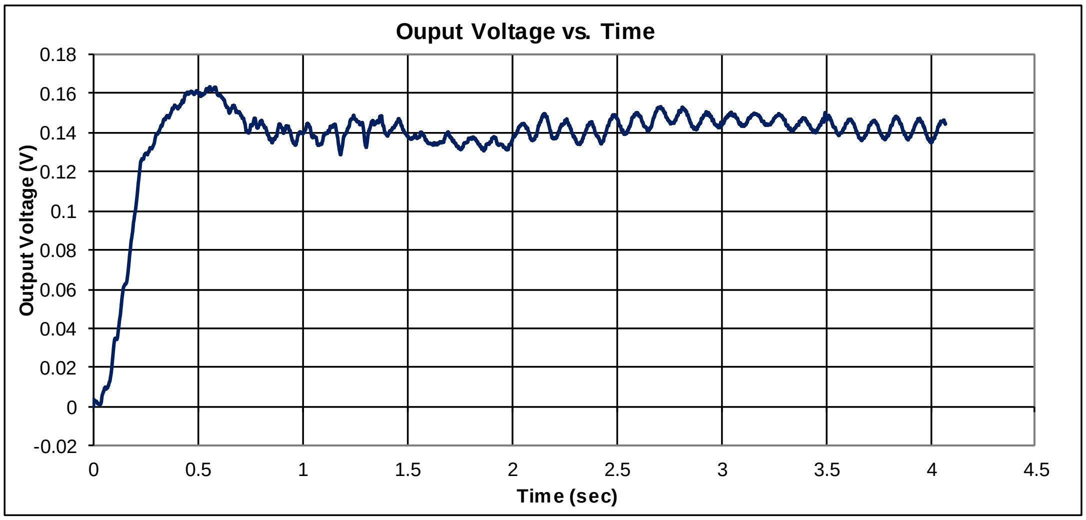
Test No:	MWP-3
Date:	7/11/2014
System / Test Article:	4-Cable Median Barrier
SP Location / Component:	US Anchor
Additional Notes:	NA

String Potentiometer Information:

String Pot No.:	27039202
Calibration Factor:	19.4483 mV/V/in.
Input Voltage (excitation):	10 Volts
Gain:	1
Full Scale Load:	1
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Max. Displacement:	0.84 in.
Time of Max. Displacement:	0.555 sec
Event Duration:	5.061 sec
Final Displacement:	0.74 in.



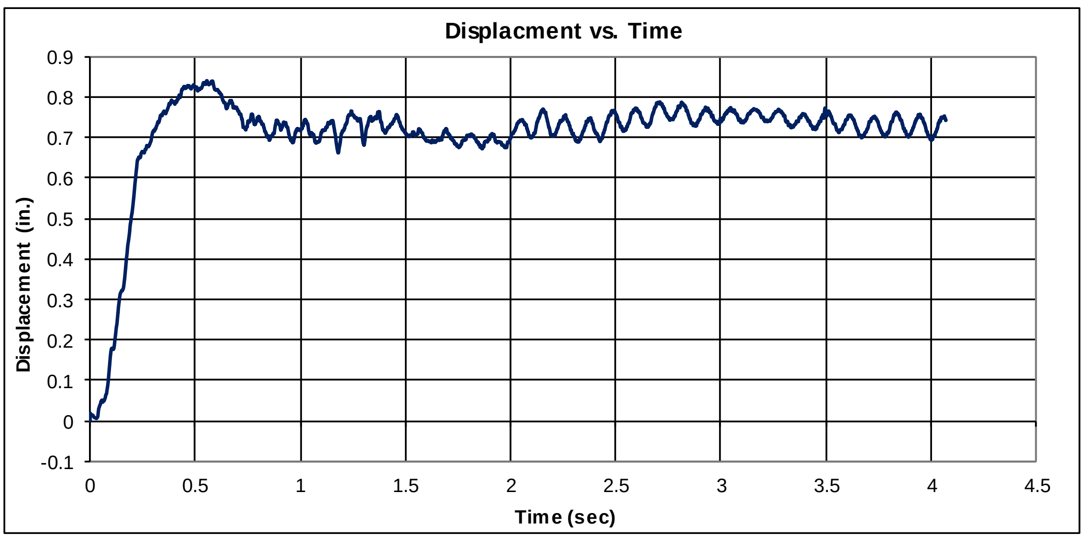


Figure J-6. String Potentiometer Data, Test No. MWP-3

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